NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

THE EXTENSION OF TECHNOLOGY AND THE CONTROL OF PRODUCTION COSTS IN ADVANCED SATELLITE SYSTEMS

by

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June 1989

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The Extension of Technology and the Control of Production Costs in Advanced Satellite Systems

by

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Submitted in partial fulfillment of the
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ABSTRACT

Advances in technology can affect production costs which in turn can be affected by a contractor's financial condition. The purpose of this thesis is to test the relationships between advances in technology, production costs and financial conditions of contractors. The analysis is conducted using data from a sample of satellite systems.

This thesis describes the relationships between technology and production cost with the goal of developing a model which can be used for projecting production cost as technology advances. The findings indicate that production cost is significantly associated with measures of technology and with measures of development cost. The relationships identified lay the foundation for projecting production cost.

This thesis also examines relationships between control over production cost by contractors and their financial condition. The analysis suggests that aspects of financial condition may be indicators of a contractors ability to control production cost, but data limitations prohibit strong conclusions.

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I. INTRODUCTION

A. THESIS OBJECTIVE

The purpose of this thesis is to determine the relationships between advances in technology, production costs and financial conditions of contractors. The analysis is conducted using data for a sample of fourteen complex satellite systems.

This thesis topic was selected as an extension of a project completed by Dr. Willis R. Greer, Jr. [Ref. 1]. His project analyzed the relationships between measures of technology (and technology advance) and research and development costs. This thesis will conduct a similar analysis but emphasize relationships between technology and production costs as technologies advance. Additionally, this thesis will document the relationships between control of production costs and contractor financial condition.

B. BACKGROUND

Dr. Greer's study examined the techniques currently available for costing state-of-the-art (SOA) extension contracts by surveying literature dealing explicitly with SOA measurement and costing. As there was general recognition that the cost of an SOA extension relates to the scale of the undertaking, most of the research done to date has concentrated on measuring the amount of SOA extension

represented by a sample set of efforts. The study employed various techniques to combine design variables in an effort to produce a single measure of the SOA for a given system.

Dr. Greer also studied the direct relationship between the scale of an SOA extension and development cost, with disappointing results. He discovered that cost estimates made early in the life of a project were plagued with error; therefore the focus of his study was to develop a cost estimating model that was demonstrably workable for both prediction and cost control uses.

In Dr. Greer's study, eighteen variables or composite variables that could be used to describe satellite technology were identified. A factor analysis was then run with eleven of the eighteen variables factored in its final form. They clustered onto four factors with 81.7% of the variance explained. These four factors were used to describe basic dimensions of technology.

His next step was to calculate factor scores for each of the eighteen systems in the data set. An ellipsoid model was then fit to the factor scores and used to determine a summary measure of the level of technology embodied in each satellite. The technology embodied in individual satellites was measured by the radial distance from the origin.

Dr. Greer's purpose of developing SOA measures was to facilitate prediction of the cost of developing new technological systems, which is a necessary initial step in

any attempt to control costs. His next step was therefore to search for statistical associations between (A) the degree to which a system's technology is extended and (B) the level of activity required to bring this extension about.

The technological objective of a development project and the technology SOA of the closest existing satellite were used to identify the development task by referencing the technological distance separating the two. Three more detailed measurement concepts were then developed: <u>reach</u>, <u>advance</u>, and <u>redesign</u>. <u>Reach</u> measures the total technological complexity, or the overall ambition of the project. <u>Advance</u> represents the "invention" aspects or the "true" SOA progress required [Ref. 1:P.V.]. The <u>redesign</u> portion represents a movement parallel to an old SOA surface, which reflects a tradeoff between different dimensions of technology.

<u>Testing the Time Hypothesis</u>

The first hypothesis that Dr. Greer tested was that the difficulty of the development task, as measured by the <u>time required for its completion</u>, is a function of the three measures of technological spread. His results were:

Time = 52.86+218.93 Advance	-34.28 Redesign	-17.37 Reach	
t statistics (3.69)	(1.45)	(0.47)	
Significance .001	.085	.322	

Variance explained (R^2) .791

Adjusted R^2 .728

Standard error of the estimate 8.745

The regression results were highly significant. Advance was by far the most important determinant of development time. Neither redesign nor reach were statistically significant.

Cost Prediction Hypothesis

Dr. Greer then hypothesized that development cost would be a function of development time. Additionally, he argued that cost would not be a smooth function of development time. If a program takes longer then its intended completion date, it becomes more expensive to compress the required accomplishment into an increasingly smaller time horizon. He thus postulated that there is a "natural" project time, and that the residuals from this natural time may influence cost. Again, his multiple regression produced good results,

Cost = -61357+4793.1 Predicted time+7391.4 Residual Time		
t statistics	(3.12)	(2.47)
Significance	.004	.013
Variance explained (R^2)	.590	
Adjusted R^2	.516	
Standard error of the estimate	82647	

Cost Control

In order to control costs, the variances between predicted and actual costs must be explained. The regressions developed by Dr. Greer provided a basis for doing so.

He first used advance, redesign and reach in the "time" regression to predict the time that would be required for the system's development. The predicted time was then input to the "cost" regression (with the residual set to zero) to provide an _ex ante_ prediction of development cost.

His next step was to compare the _actual_ time for the project to the predicted time in order to determine the residual. He then used the cost regression again in order to calculate a new cost estimate considering the residual time for the project. The difference between the _ex ante_ cost estimate and the cost estimate based on the project's actual time was termed the "variance due to time" or the portion of the total variance that can be attributed to the cost consequences of time delays.

Actual cost was then compared with the cost estimate based on actual time to determine a "cost control variance". This variance indicates the quality of cost control for the project. The resulting data will be presented and further explained in Chapter II.

This thesis will differ from Dr. Greer's study in two respects:

1. Dr. Greer's analysis considered the "development costs" of each system. This analysis will consider "production costs" of each system. Production cost data for fourteen individual systems was obtained and an attempt was made to explain production cost using variables that were

derived in Dr. Greer's study. The central focus of the thesis is to explain production cost in terms of two sets of available variables: (A) a set reflecting technology and its extension (advance, redesign, and reach) and, (B) a set reflecting aspects of cost and cost control during development. I have hypothesized that because technological advance represents mainly the "invention" aspect of a project, it will have only a limited relationship to production costs.

An attempt will be made to explain production cost using development costs and estimated costs derived through regression analysis. I have hypothesized that as development costs increase production costs will also increase, as high development costs may indicate a more complex system resulting in increased production costs.

2. This thesis will also create measures of cost control (cost overruns and cost underruns) by comparing actual production costs with production costs predicted on the basis of the known technology and development cost measures. This data will then be compared with measures of contractor financial condition (e.g. financial ratios) designed to reflect aspects of contractor financial status and financial health. Financial data has been obtained for most of the satellite systems tested and based on that data, I have hypothesized that a company in good financial health will

have better cost control and will thus have a better chance of eliminating cost overruns.

C. RESEARCH METHODOLOGY

Two research methodologies, archival and analytical, will be used to develop and analyze the data presented in this thesis. The following paragraphs describe how each method will be used.

1. Archival Research

Archival Research, in the form of literature review, will be conducted in order to develop a methodology for measuring the degree of technology in a system and advances in technology beyond that embodied in predecessor systems. Additionally, literature review will be conducted to develop a means of predicting production costs as a function of a system's technology and advance in technology.

A financial statement review will then be conducted in order to develop measures of contractor financial condition. These measures will be designed to reflect aspects of contractor financial status and financial health, to be used in developing hypotheses stating expected relationships between financial condition and cost control.

2. Analytical Research

Analytical research utilizing inductive and deductive reasoning will be used to develop hypotheses and

analyze the data. Statistical procedures, such as regression and correlation, will be used to test hypotheses.

D. THESIS ORGANIZATION

The following is an organizational outline and description of the remaining chapters:

Chapter II will provide a detailed review of Dr. Greer's study. His methods of sample and data collection will be explained, followed by a detailed description of his procedures for arriving at technology measures of advance, redesign and reach. His hypotheses will again be discussed, as well as an explanation of the derived variances between predicted and actual development costs. The chapter will conclude with a presentation of Dr. Greer's data to be used for further hypotheses testing in Chapter III.

Chapter III will report results of testing of hypotheses about associations between measures of production costs and measures of technology. Regression analysis will be used for testing hypotheses and for constructing measures of predicted production costs as a function of measures of technology and development costs. This chapter will also contain a discussion of cost control through comparison of actual production costs with predicted production costs. The resulting cost overruns and cost underruns will be used for hypotheses testing in Chapter V.

Chapter IV will discuss the expected relationships between cost control and contractor financial conditions. The use of financial ratios to represent contractor financial condition will be discussed. The meaning and calculation of specific ratios will be described as well as the possible effects on cost control. The chapter will conclude with a presentation of financial ratios accumulated from satellite system contractors from the year in which the project was contracted.

Chapter V will report the results of testing hypotheses between cost control and contractor financial condition. Through graphing and correlation, this chapter will determine if cost overruns/underruns are associated with financial ratios.

Chapter VI will summarize conclusions from the tested hypotheses and offer recommendations.

II. PRELIMINARY ANALYSIS: A REVIEW OF DR. GREER'S STUDY

A. INTRODUCTION

This chapter will provide a detailed review of Dr. Greer's study. Specifically: Dr. Greer's methods of sample and data collection and procedures he used to arrive at technology measures of advance, redesign and reach. The chapter will conclude with a presentation of new measures of production costs to be used for hypothesis testing in Chapter III.

B. METHODS OF SAMPLE AND DATA COLLECTION

TABLE 2.1

RELEVANT SATELLITE DEVELOPMENT COST DATA

System	Min Dist Predecessor	R&D Cost FY 86$	Devel Time(mo)	Advance	Redesign	Reach
H	G	73594.4	25	0.01947	0.37529	0.76986
O	F	116580.0	27	0.02398	0.41191	0.93837
L	H	37228.4	32	0.01076	0.26210	0.78737
J	H	155522.8	46	0.10584	0.44910	0.93328
N	F	32585.5	28	0.00719	0.10878	0.91366
M	H	319498.7	37	0.03647	0.17506	0.82829
B	H	91707.4	37	0.05194	0.27101	0.85233
Q	F	64383.3	37	-0.01799	0.25978	0.87590
P	O	121932.3	33	-0.02440	0.13829	0.90234
E	L	108084.9	37	0.00867	0.09139	0.80131
K	N	14943.2	36	0.05180	0.21674	0.98883
R	P	180652.8	56	0.18031	0.21766	1.15432
C	M	157820.4	64	0.22497	0.38644	1.14932
I	H	451274.0	86	0.18782	0.25399	1.04977

The relevant portion of data from Dr. Greer's analysis is shown above. Of the original eighteen systems, four were omitted because relevant cost data were unavailable. The development of the three technology measures (advance, redesign and reach) - to be described below - were based on all eighteen systems.

These remaining fourteen systems represent satellites launched between 1966 and 1986, with letters assigned randomly for identification. The reported cost figures are "nonrecurring" development costs provided by the Air Force for each system. The costs have been adjusted to constant 1986 dollars by using the OSD 3600 Escalation Index of prices for development work. The "time" column reports the time elapsed, in months, from awarding the contract to the first launch of the satellite. (The minimum distance predecessor will be explained later). The figures for advance, redesign and reach were calculated by Dr. Greer using a multi-step procedure as follows.

He selected variables that describe technology embedded in satellites. Data describing 85 technical characteristics were available [Ref. 1:p. 47]. Some of the 85 properties included in the data set were considered design objectives, but others were by-products of the design. Therefore, Dr. Greer relied on technical expertise in identifying and reconstructing relevant variables. Through conferences with technical experts, consensus identification of the following

eighteen variables or composite variables to be used to describe satellite technology was achieved:

Attitude Control System (ACS) variables:

ACS1--Reciprocal of Pointing accuracy

ACS2--Primary stabilization method

ACS3--Maneuverability

Apogee Kick Motor (AKM) variables:

AKM1--Specific impulse

AKM2--Propellent weight/Dry weight

Communications variable:

Comm--Power required

Electrical power systems variables:

EPS1--Battery capacity

EPS2--Beginning of life power/Array area, compensated for stabilization and array deployment

EPS3--Array topology

Mission or Environmental variables:

LIFE--Design life

NHARD--Nuclear hardening

LAUNCH--Launch method

QUALS--Quality percent class S

APOGEE--Orbital apogee *Design life* (% Quality S+0.8 % Quality B) / 10000

DESIGN--Design life / (% Quality S+.1% Quality B)

Structure variable:

STRUC--Percent deployed weight

Thermal variable:

THERM--Max temperature - Min temperature

Tracking Telemetry Control variable:

TTC--Autonomous operating days

The eighteen variables were determinable for each of the satellites with one exception; THERM was missing for satellite R, but the mean value of THERM was inserted to avoid distorting later portions of the analysis.

Values of all eighteen variables for all satellites were then loaded into an $SPSS^x$ data file. A factor analysis was then run resulting in high coefficients of variation and many significant correlations [Ref. 1:pp. 53, 54].

Dr. Greer determined that the number of variables should be reduced to enable a more meaningful analysis of the data. Accordingly, he selectively eliminated some of the eighteen variables. STRUC was eliminated because the engineers felt some of the data was incorrect. The seventeen remaining variables were then subjected to a principal components factor analysis using the varimax procedure for orthogonal rotation [Ref. 1:p. 52]. Variables with large (greater than 0.5) negative loadings were eliminated. This eliminated DESIGN, ASC3 and EPS2. He than eliminated QUALS because it had no substantial factor loading. The remaining thirteen

variables were factored again and clustered nicely onto four factors with 78.5% of the variance explained. He than attempted to maximize the percentage of variance explained. He found that by eliminating ASC1 and TTC but retaining LAUNCH the variance explained reached a maximum of 81.7%.

Factor Interpretation

Dr. Greer's conclusions as to the nature of the four factors that describe technology embedded in a satellite were as follows:

He described FACTOR 1 as MISSION. To describe mission, the requirements were specified in terms of APOGEE, LIFE, COMM and LAUNCH:

APOGEE--(Orbital apogee *Design life* (%Quality S+ 0.8% Quality B) /10000)--Add to LIFE a description of the required apogee and quality levels, in percentages S and B.

LIFE--What must the design life of the satellite be?

COMM--While the variable is actually required power for communications equipment, it should be easily estimable from mission specifications.

LAUNCH--How will the satellite be launched?

FACTOR 2 was described as an indirect measure ORBITAL. The apogee kick motor was used in obtaining the correct orbit. It was determined that if the designer knows the MISSION, the launch method and the required apogee and shape of the orbit,

then rough specifications of the two AKM variables can be determined:

AKM2--Propellent weight/Dry weight.

AKM1--Specific impulse.

FACTOR 3 was determined to be an indirect description of the electrical power system technology.

EPS3--Array topology.

EPS1--Battery capacity

ACS2--Primary stabilization method. Dr. Greer determined this to be integrally related to array topology due to its implications for array deployment, he therefore combined these three variables to make up a single factor labeled ELECTRICAL POWER.

FACTOR 4 was described as ENVIRONMENT with the following two environmental variables on this factor:

THERM--Max temperature - Min temperature.

NHARD--Nuclear hardening.

The following summary of the four factors describe the technology embedded in a satellite and account for 81.7% of the variance in the sample:

FACTOR	LABEL	VARIABLES
1	MISSION	APOGEE, LIFE, COMM, LAUNCH
2	ORBITAL	AKM2, AKM1
3	ELECTRICAL POWER	EPS3, ACS2, EPS1
4	ENVIRONMENT	THERM, NHARD

C. MEASURES OF TECHNOLOGY

Dr. Greer's next step was to construct a table of factor scores for all eighteen systems. The SPSS^{X} regression method was used to determine factor scores with the following results:

TABLE 2.2

FACTOR SCORES

SYSTEM	FACT 1	FACT 2	FACT 3	FACT 4
A	0.5481	1.4894	1.4514	1.3038
B	-0.7021	-0.6149	0.8253	-0.8771
C	1.4523	-1.1906	0.3233	2.3646
D	-0.2591	1.1941	0.8042	0.0857
E	-0.8919	-0.7342	0.4668	-0.6761
F	-0.5195	0.6648	-1.3337	0.8363
G	-0.2870	-1.3133	-1.7576	0.8937
H	0.4619	-0.8923	-0.4650	-1.1932
I	2.1776	-1.0966	0.4696	-0.3093
J	-1.4171	-1.0918	1.5999	-0.0233
K	-1.0725	0.9872	0.2058	0.4739
L	-0.9641	-0.6474	0.0670	-0.2184
M	-0.1629	-0.8299	0.2157	-0.4064
N	-1.1595	0.7442	-1.0434	1.0676
O	0.6814	0.9718	-0.4915	-1.6992
P	0.1755	0.7231	-0.4819	-0.8667
Q	0.7529	0.4861	-1.7235	-0.4232
R	1.1859	1.1505	0.8674	-0.3126

The figures for advance, redesign and reach (Table 2.1) were calculated from the four factor scores above through construction of an ellipsoid model developed by E.N. Dodson [Ref. 2:pp. 391-408]. Using the four factor scores as basic

technology variables, an ellipsoid of the following form was fit to the data:

$$\frac{X_1^2+X_2^2+X_3^2+X_4^2}{A^2+A^2+A^2+A^2} = 1$$

Where:

Xi=Factor Scores

Ai=Parameters determined by the ellipsoid fitting procedure. The result was a hypersurface in 4-dimensional space which represented the "average" SOA for the sample of satellites.

The level of SOA technology embodied in each satellite was then determined by inserting the factor scores for each satellite into the industry technology ellipsoid model. The technology measure for each satellite was then described as the distance from the origin to the data point and is a function of the four distinct measured scores.

A general measurement concept was then defined, called technology distance, which permits the measurement of distance between any two points within an N-dimensional space. Using this idea of technology distance, Dr. Greer created the measures advance, redesign and reach (Table 2.1) relevant to capturing technology complexity and extension. Reach represented the total technological complexity embodied in an individual satellite and was measured as the distance

from the origin to the point (in 4-dimensional space) held by each individual satellite. Advance represented the increment in technology from a predecessor satellite to the next one. Advance was measured as the difference in reach between a satellite and its predecessor. Redesign represented tradeoffs made in the design process between the four dimensions of technology. Redesign was measured in terms of a lateral shift along a technology SOA hypersurface.

D. RELATIONSHIP BETWEEN TECHNOLOGY AND DEVELOPMENT COST

Dr. Greer's first hypothesis was that development time depends on the technological complexity of the task. He ran a multiple regression of development time to advance, redesign and reach. The result was:

Time =	52.86+218.93 Advance	-34.28 Redesign	-17.37 Reach
t statistics	(3.69)	(1.45)	(0.47)
Significance	.001	.085	.322

Variance explained (R^2) .791

Adjusted R^2 .728

Standard error of the estimate 8.745

Dr. Greer's results indicate that advance was the most important determinant of development time and neither redesign nor reach was statistically significant. Table 2.3 and Figure 2.1 show the residuals and a plot of predicted versus actual time.

TABLE 2.3

RESIDUALS FROM TIME REGRESSION

ACTUAL Time (months)	PREDICTED Time (months)	RESIDUAL
25	30.89	-5.89
27	27.69	-.69
32	32.56	-.56
28	34.84	-6.84
46	44.43	1.57
37	40.46	-3.46
37	40.14	-3.14
37	24.8	12.2
33	27.11	5.89
37	37.71	-.71
36	39.6	-3.6
56	64.83	-8.83
64	68.91	-4.91
86	67.04	18.96

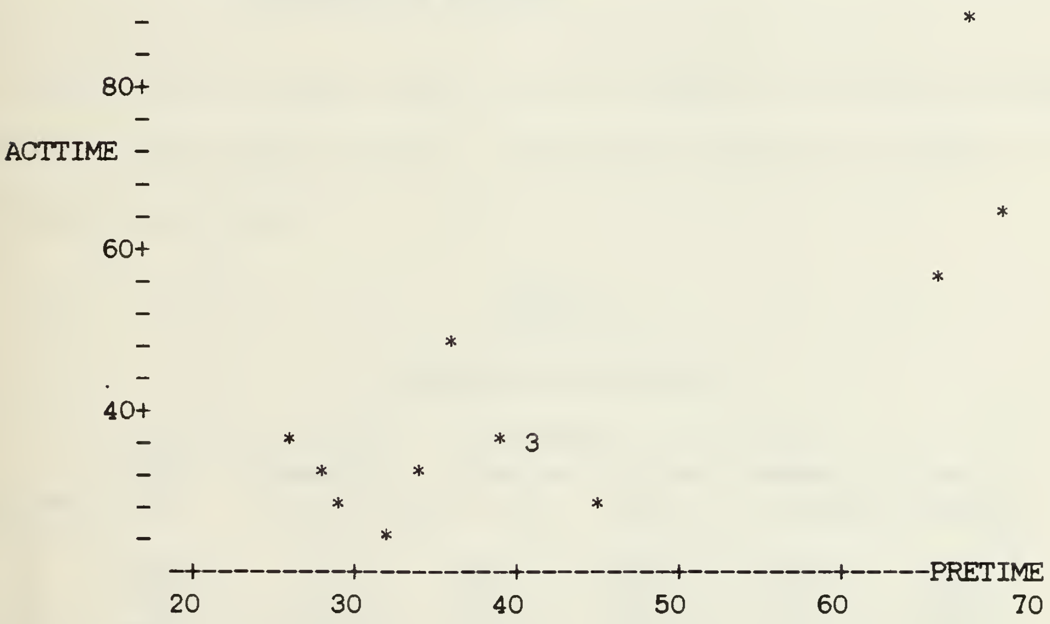


Figure 2.1 Predicted Versus Actual Development Time in Months

Dr. Greer's second hypothesis revolved around the fact that development cost may not be a smooth function of

development time. If a program takes longer than intended, it may be more costly to accomplish the required project in less time. He therefore took the predicted times as the natural time to complete a project and the residuals as departures from natural time to come up with the following hypothesis:

Development Cost = f(Predicted time, Residual) where Residual = Actual time - Predicted time. The result was:

Cost = -61357+4793.1 Predicted Time+7391.4 Residual

t statistics	(3.12)	(2.47)
Significance	.004	.031
Variance explained (R^2)		.590
Adjusted R^2		.516
Standard error of the estimate	82647	

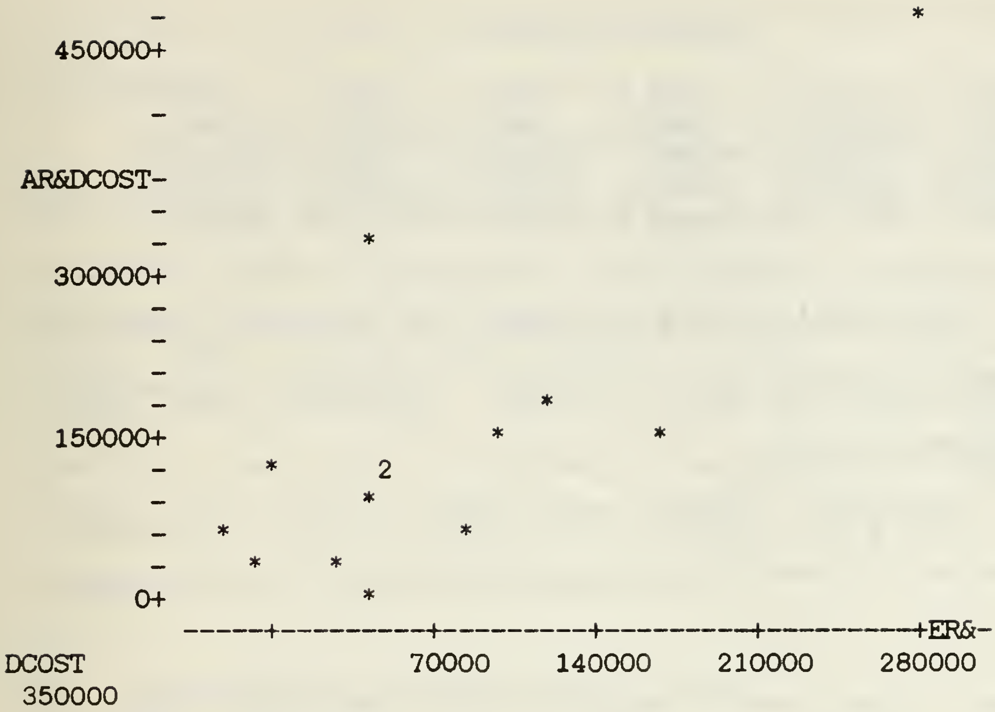


Figure 2.2 Plot of Predicted Versus Actual Cost in Thousands of Dollars

Dr. Greer's next step was to explain variances between predicted and actual costs. He thus constructed Table 2.4 in the following way:

TABLE 2.4

PERFORMANCE VARIANCES

System	Ex Ante Cost Est	Cost Est Based on Actual Time	Variance Due to Time	Actual Cost	Cost Control Variance	Total Variance
H	86693.6	43171.8	-43521.8	73594.4	30422.6	-13099.2
O	71378.8	66256.4	-5122.4	116580.0	50323.6	45201.2
L	94692.3	90575.8	-4116.5	37228.4	-53347.4	-57463.9
J	105629.1	55081.5	-50547.6	32585.5	-22496.0	-73043.6
N	151593.0	163210.9	11617.9	155522.8	-7688.1	3929.8
M	132567.0	107001.7	-25565.2	319498.7	212497.0	186931.7
B	131031.5	107834.1	-23197.4	91707.4	-16126.7	-39324.1
Q	57540.8	147671.9	90131.1	64383.3	-83288.6	6842.5
P	68571.3	112126.8	43555.5	121934.3	9805.5	53361.0

TABLE 2.4 (cont'd)

E	119390.3	114144.5	-5245.8	108084.9	-6059.6	-11305.4
K	128438.5	101848.3	-26590.3	14943.2	86905.1	-113495.3
R	249372.7	184120.6	-65252.1	180652.8	-3467.8	-68719.9
C	268926.2	232652.4	-36273.8	157820.4	-74832.0	-111105.8
I	259983.1	400111.4	140128.3	451274.0	51162.6	191290.9

1. The individual system's values for advance, redesign and reach were entered in the "time" regression to predict system development time.

2. The predicted time was input into the "cost" regression to calculate the <u>ex ante</u> prediction of development cost.

3. Actual time was compared to predicted time to determine residual. The cost regression was again used with values for both variables to construct a new cost estimate considering actual time residual of the project in order to produce the "Cost Est Based on Actual Time" column.

The difference between ex ante cost estimate and cost estimate based on actual time was termed "Variance Due to Time". This figure was determined to be the best estimate of the portion of total variance attributed to cost consequences of time delays where negative figures are favorable and positive figures are unfavorable.

The difference between actual cost and cost estimate based on actual time was termed "Cost Control Variance" with a negative figure again being favorable.

Total variance is therefore the combined total of the two variances.

Dr. Greer's results indicate an unfavorable cost variance due to time for programs P and I (timing problems) and O and M (cost control problems). His results indicate a favorable total cost variance for programs J (good timing) and L and K (good cost control). Project Q had an unfavorable variance due to time but a favorable cost control variance which resulted in the total cost variance being an insignificant amount.

E. NEW MEASURES OF PRODUCTION COSTS

Relevant Satellite Production Cost Data

The data relevant to my hypothesis in chapter three is as follows:

TABLE 2.5

DATA FOR PRODUCTION COST HYPOTHESES TESTING

System	Min Dist Predecessor	Prod Cost FY 86$	Devel Time(mo)	Advance	Redesign	Reach
H	G	50414.0	25	0.01947	0.37529	0.76986
O	F	142662.0	27	0.02398	0.41191	0.93837
L	H	23144.1	32	0.01076	0.26210	0.78737
J	H	118752.3	46	0.10584	0.44910	0.93328
N	F	33797.9	28	0.00719	0.10878	0.91366
M	H	387034.1	37	0.03647	0.17506	0.82829
B	H	93931.8	37	0.05194	0.27101	0.85233
Q	F	84144.1	37	-0.01799	0.25978	0.87590
P	O	169721.8	33	-0.02440	0.13829	0.90234
E	L	162283.0	37	0.00867	0.09139	0.80131
K	N	17697.0	36	0.05180	0.21674	0.98883
R	P	594167.0	56	0.18031	0.21766	1.15432
C	M	93730.0	64	0.22497	0.38644	1.14932
I	H	311833.0	86	0.18782	0.25399	1.04977

All data columns are the same as Table 2.1 with the exception of "Prod Cost FY86$". These reported production cost figures are "nonrecurring" production costs provided by the Air Force for each system, adjusted to constant 1986 dollars by using the OSD 3020 Escalation Index of prices for production work. Although not analyzed by Dr. Greer, the production cost data will be central to the further analysis in this thesis.

F. SUMMARY

This chapter has reviewed the previous analysis conducted by Dr. Greer. The first purpose of the chapter was to outline steps Dr. Greer conducted in: (A) developing technology measures and; (B) analyzing the relationships between technology extension and development costs. The second purpose of the chapter was to present the data for several variables that will be used in later chapters. Dr. Greer's analysis has provided three measures of technology or technology extension (advance, redesign, and reach), three measures of development cost (actual, ex ante, and estimated based on actual time) and two cost variances (variance due to time and cost control variance). Data for each of these variables has been presented in various tables. The next chapter will attempt to document relationships between some of these variables and production costs.

III. TECHNOLOGY AND PRODUCTION COSTS

A. INTRODUCTION

This chapter will test hypotheses between measures of production costs and measures of technology. Regression analysis was used for testing hypotheses and for constructing measures of predicted production costs as a function of measures of technology and development costs. The results are presented in this chapter. This chapter will also discuss cost control through comparison of actual production costs with predicted production costs. The resulting cost overruns and cost underruns will be used for hypotheses testing in Chapter V.

B. HYPOTHESES TESTING

The data relevant to this portion of the analysis are shown in Table 3.1. The reported R&D cost figures are "nonrecurring" development costs provided by the Air Force for each system. The costs are adjusted to constant 1986 dollars by using the OSD 3600 Escalation Index of prices for development work. The production cost figures, also provided by the Air Force, are adjusted to constant 1986 dollars by using the OSD 3020 Escalation Index of prices for production costs.

TABLE 3.1

DATA FOR PRODUCTION COST HYPOTHESES TESTING

System	Prod Cost	Advance	Redesign	Reach	R&D Cost
H	50414	0.01947	0.37529	0.76986	73594
O	142662	0.02398	0.41191	0.93837	116580
L	23144	0.01076	0.26210	0.78737	37228
J	118752	0.10584	0.44910	0.93328	155523
N	33798	0.00719	0.10878	0.91366	32586
M	387034	0.03647	0.17506	0.82829	319499
B	93932	0.05194	0.27101	0.85233	91707
Q	84144	-0.01799	0.25978	0.87590	64383
P	169722	-0.02440	0.13829	0.90234	121932
E	162283	0.00867	0.09139	0.80131	108085
K	17697	0.05180	0.21674	0.98883	14943
R	594167	0.18031	0.21766	1.15432	180653
C	93730	0.22497	0.38644	1.14932	157820
I	311833	0.18782	0.25399	1.04977	451274

Test of First Hypothesis

The first set of hypotheses concern the relationship between production cost and technology measures. Can production cost be explained directly from knowing the degree of technological extension or complexity of a system? I have hypothesized that because advance represents mainly the "invention" aspect of the project or the increment in technology from a predecessor satellite to the next one, it will have only a limited affect on production costs. As redesign had little affect on R&D costs it is hypothesized that it will again have little affect on production costs. On the other hand, reach represents the overall technological extension of the system. While costs to advance or redesign a system might reasonably be expected to cause R&D costs, production costs to build the system might be more highly

correlated with the overall technological complexity as reflected by reach. To test the first hypotheses a multiple regression was run. The result was:

The regression equation:
PRODCOST = 182772 + 1138059 ADVANCE - 593915 REDESIGN + 68493 REACH

Predictor	Coef	Stdev	t-ratio	p
Constant	182772	558617	0.33	0.750
ADVANCE	1138059	1008226	1.13	0.285
REDESIGN	-593915	402825	-1.47	0.171
REACH	68493	624697	0.11	0.915

s = 148655   R-sq = 36.2%   R-sq(adj) = 17.1%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	3	1.25511E+11	41836974080	1.89	0.195
Error	10	2.20982E+11	22098206720		
Total	13	3.46493E+11			

SOURCE	DF	SEQ SS
ADVANCE	1	72779866112
REDESIGN	1	52465405952
REACH	1	265648528

Unusual Observations

Obs.	ADVANCE	APROCOST	Fit	Stdev.Fit	Residual	St.Resid
R	0.180	594167	337766	91321	256401	2.19R

R denotes an obs. with a large st. resid.

Taken as a whole the regression is not very significant. In addition, the coefficients for all three technology variables are insignificant. The findings suggest no <u>direct</u> relationship between production cost and the various measures of technology.

Test of Second Hypothesis

I have hypothesized that as development costs increase, production costs will also increase, as high development costs may indicate a more complex system, resulting in increased production costs. To test this hypothesis a regression was run with the following results:

```
The regression equation:
PRODCOST = 38745 + 0.904 R&DCOST

Predictor         Coef        Stdev     t-ratio        p
Constant         38745        53501        0.72    0.483
AR&DCOST        0.9040       0.2990        3.02    0.011

s = 128024       R-sq = 43.2%     R-sq(adj) = 38.5%

Analysis of Variance

SOURCE        DF           SS           MS          F        p
Regression     1 1.49813E+11 1.49813E+11       9.14    0.011
Error         12 1.96680E+11 16390017024
Total         13 3.46493E+11

Unusual Observations
Obs.AR&DCOST  APROCOST   Fit Stdev.Fit  Residual  St.Resid
R     180653    594167  202051    36562    392116     3.20R
I     451274    311833  446685    99847   -134852    -1.68X

R denotes an obs. with a large st. resid.
X denotes an obs. whose X value gives it large influence.
```

A plot of R&D Cost versus Production Cost is shown below.

```
        -
  600000+                   *
        -
PRODCOST-
        -
        -
  400000+                                 *
        -
        -                                              *
        -
        -
  200000+
        -            *2
        -                 *
        -       *  *      *
        -    **  *
       0+  *
       --+---------+---------+---------+---------+------R&DCOST
         0    100000    200000    300000    400000       500000
```

Figure 3.1 R&D Cost Versus Production Cost in Thousands of Dollars

The regression equation and plot indicate a strong relationship between R&D costs and production costs. Costly R&D indicates costly production. However, the data also clearly indicate that system R is an outlier. System R was eliminated and the regression run a second time. The resulting regression equation and plot with system R eliminated were as follows:

The regression equation:
APROCOST = 22055 + 0.804 AR&DCOST

Predictor	Coef	Stdev	t-ratio	p
Constant	22055	21660	1.02	0.330
AR&DCOST	0.8036	0.1211	6.63	0.000

s = 51585   R-sq = 80.0%   R-sq(adj) = 78.2%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	1	1.17103E+11	1.17103E+11	44.01	0.000
Error	11	29271394304	2661035776		
Total	12	1.46375E+11			

Unusual Observations

Obs.	AR&DCOST	APROCOST	Fit	Stdev.Fit	Residual	St.Resid
M	319499	387034	278809	26615	108225	2.45R
I	451274	311833	384705	40984	-72872	-2.33X

R denotes an obs. with a large st. resid.
X denotes an obs. whose X value gives it large influence.

A plot of R&D Cost versus Production Cost is shown below.

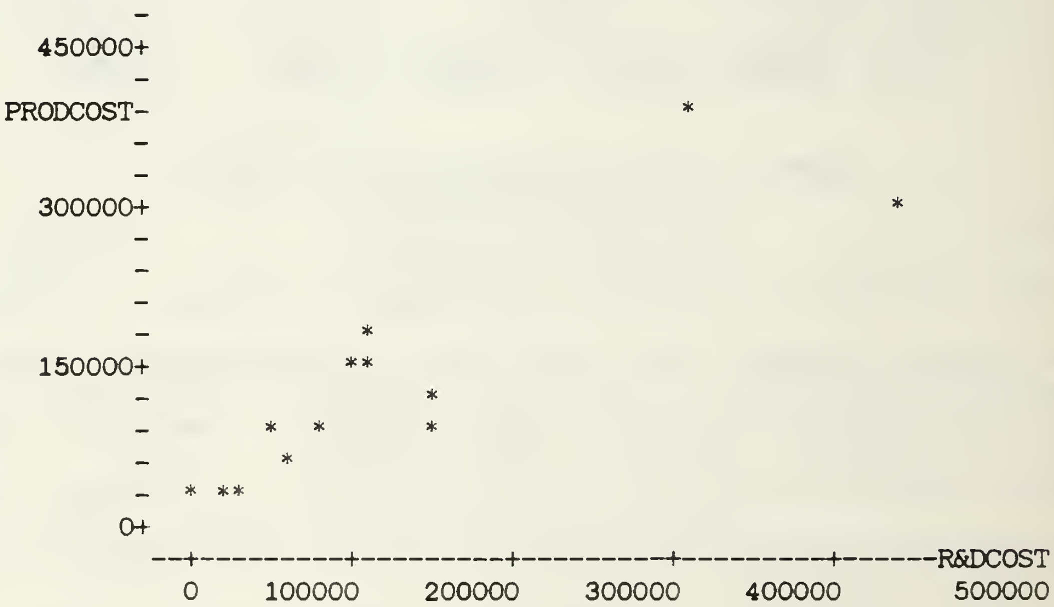


Figure 3.2 R&D Cost Versus Production Cost in Thousands of Dollars

Upon removing system R the results indicate an even stronger relationship between the two variables. Adjusted R^2 has increased from .38 to .78, consistent with system R masking the strong underlying positive association between R&D cost and production cost. In essence, the relationship between R&D cost and production cost simply reflects the size or scale of the programs.

A further question of interest is whether production cost may in fact be related to technology, but the relationship is hidden because of the failure to control for scale effects.

To test this idea, I constructed a ratio of R&D to production cost (R&D cost/Production cost) labeled the "Development Premium Ratio". Variance in this ratio captures variance in the relationship between development and production cost while controlling for scale. The question of interest is now whether variance in the development premium ratio can be explained by the technological complexity of the systems. The following reasoning suggests some possible relationship.

The outcome of a development project is the initial prototype of each satellite system. The cost of this initial system includes: (A) the "pure" development cost of extending technology and (B) manufacturing costs associated with construction. Pure development costs will be non-recurring whereas construction costs will recur with each additional unit produced.

If the cost of developing a project required zero extension of technology then pure development cost would be zero and the cost of the initial system would be equal to the cost of producing additional units. The resulting development premium ratio would thus be equal to zero and there would be no premium to extending technology. If the opposite case is assumed where the cost of developing a project requires a large extension of technology then the pure development costs would be substantial. The development cost premium would therefore be large with a development premium ratio greater than zero. It can thus be hypothesized that if the development cost premium is driven by the technological complexity of the task, then the ratio should be predictable using the technological measures of advance, redesign and reach. Positive associations between the development premium ratio and technology measures is expected.

Test of Third Hypothesis

I have hypothesized that because advance represents the increment in technology from a predecessor satellite to the next one, measured as the difference in reach between a satellite and its predecessors, it will have a strong relationship to the development premium ratio. The regression results were as follows:

The regression equation:
Development Premium Ratio = 0.919 + 3.11 ADVANCE

Predictor	Coef	Stdev	t-ratio	p
Constant	0.91931	0.09872	9.31	0.000
ADVANCE	3.110	1.094	2.84	0.016

s = 0.2887   R-sq = 42.4%   R-sq(adj) = 37.1%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	1	0.67371	0.67371	8.09	0.016
Error	11	0.91658	0.08333		
Total	12	1.59030			

Unusual Observations

Obs.	ADVANCE	DP	Fit	Stdev.Fit	Residual	St.Resid
L	0.011	1.6085	0.9528	0.0923	0.6558	2.40R
C	0.225	1.6838	1.6189	0.2046	0.0648	0.32X

R denotes an obs. with a large st. resid.
X denotes an obs. whose X value gives it large influence.

The regression is significant with a strong relationship between advance and the development premium ratio. The coefficient for advance is positive and significant.

Test of Fourth Hypothesis

As redesign represents tradeoffs made in the design process between the four dimensions of technology as measured in terms of a lateral shift along a technology hypersurface, then it would again be hypothesized that there is a relationship between redesign and the development premium ratio. Since the cost of redesign should be less than the cost of advance in technology, one would expect that, while redesign should be positively associated with the development premium ratio, the association should be smaller than that for advance. The following regression supports this conclusion:

The regression equation:
Development Premium Ratio = 0.628 + 1.74 REDESIGN

Predictor	Coef	Stdev	t-ratio	p
Constant	0.6283	0.2221	2.83	0.016
REDESIGN	1.7408	0.7804	2.23	0.047

s = 0.3155 R-sq = 31.1% R-sq(adj) = 24.9%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	1	0.49531	0.49531	4.98	0.047
Error	11	1.09498	0.09954		
Total	12	1.59030			

The regression is significant and redesign has a positive coefficient, but that coefficient is smaller and less significant than the one previously found for advance.

<u>Test of Fifth Hypothesis</u>

Reach represents the total technological complexity embodied in an individual satellite measured as the distance from the origin to the point (in 4-dimensional space) held by each individual satellite. Reach captures the total complexity, not the "invention" aspects of the development program. Hence it is hypothesized that reach has little effect on causing pure development costs and little relationship with the development premium ratio. The following regression indicates reach has little significance.

The regression equation:
Development Premium Ratio = 0.176 + 1.00 REACH

Predictor	Coef	Stdev	t-ratio	p
Constant	0.1759	0.8791	0.20	0.845
REACH	1.0007	0.9629	1.04	0.321

s = 0.3628 R-sq = 8.9% R-sq(adj) = 0.7%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	1	0.1422	0.1422	1.08	0.321
Error	11	1.4481	0.1316		
Total	12	1.5903			

Unusual Observations

Obs.	REACH	DP	Fit	Stdev.Fit	Residual	St.Resid
C	1.15	1.684	1.326	0.254	0.358	1.38 X

X denotes an obs. whose X value gives it large influence.

A final multiple regression of advance, redesign and reach was then run against the development premium ratio with the following results:

The regression equation:
Development Premium Ratio = 2.27 + 4.58 ADVANCE + 0.885 REDESIGN - 1.83 REACH

Predictor	Coef	Stdev	t-ratio	p
Constant	2.267	1.013	2.24	0.052
ADVANCE	4.580	1.761	2.60	0.029
REDESIGN	0.8848	0.7246	1.22	0.253
REACH	-1.827	1.150	-1.59	0.147

s = 0.2594 R-sq = 61.9% R-sq(adj) = 49.2%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	3	0.98450	0.32817	4.88	0.028
Error	9	0.60580	0.06731		
Total	12	1.59030			

SOURCE	DF	SEQ SS
ADVANCE	1	0.67371
REDESIGN	1	0.14107
REACH	1	0.16971

Unusual Observations

Obs.	ADVANCE	DP	Fit	Stdev.Fit	Residual	St.Resid
L	0.011	1.6085	1.1099	0.1170	0.4986	2.15R

R denotes an obs. with a large st. resid.

This final regression confirms the individual hypotheses, with advance being the most significant followed by redesign and then reach. Note however that inclusion of the three measures in the model has increased the R^2 substantially from any of the three models including only the individual variables. Since our objective here is to maximally use the measures to explain production cost, this multiple regression model will be used to develop predicted production costs and production variances to be used for hypotheses testing in Chapter V.

C. DEVELOPMENT OF PRODUCTION COST VARIANCES

Production Cost Variances

In order to develop predicted production costs and production variances, consider the information contained in Table 3.2 below.

TABLE 3.2

CALCULATIONS FOR PERFORMANCE VARIANCES

System	Prod Cost	DPR	Pred DPR	Pred Prod	Prod Var	%Var
H	50414	1.45979	1.28194	57408.47	-6994.47	-12.2
O	142662	0.81718	1.02719	57408.47	29168.20	25.7
L	23144	1.60854	1.10991	33541.45	-10397.4	-31.0
J	118752	1.30965	1.44434	107677.3	11074.67	10.3
N	33798	0.96414	0.72722	44808.80	-11010.8	-24.6
M	387034	0.82551	1.07592	296955.3	90078.64	30.3
B	93932	0.97631	1.18776	77210.27	16721.72	21.7
Q	84144	0.76515	0.81446	79049.66	5094.337	06.4
P	169722	0.71842	0.62932	193753.1	-24031.1	-12.4
E	162283	0.66603	0.92383	116996.0	45286.98	38.7
K	17697	0.84438	0.88977	16794.28	902.7153	05.4
C	93730	1.68377	1.53994	102484.3	-8754.38	-08.5
I	311833	1.44717	1.43443	314601.1	-2768.16	-00.9

Note: DPR=Development Premium Ratio

In order to determine the systems' "predicted" development premium ratio, a particular system's values for advance, redesign and reach were entered into the multiple regression equation. The system's predicted development premium ratio was then divided into one, with the result multiplied by the corresponding R&D cost in order to arrive at "predicted" production cost. Note, the objective here is to create measures of predicted production costs using information available prior to actual production. This approach in essence provides a predicted production cost using known R&D costs and the three technology measures (also known prior to production.)

The difference between actual production costs and predicted production costs yielded the "production cost variance". Minus figures are favorable, positive figures are unfavorable. Finally, dividing the production cost variance by the predicted production costs and multiplying by 100 resulted in the "percentage variance". Again, minus figures are favorable.

The variances identified above have been shown graphically in Figures 3.3 and 3.4.

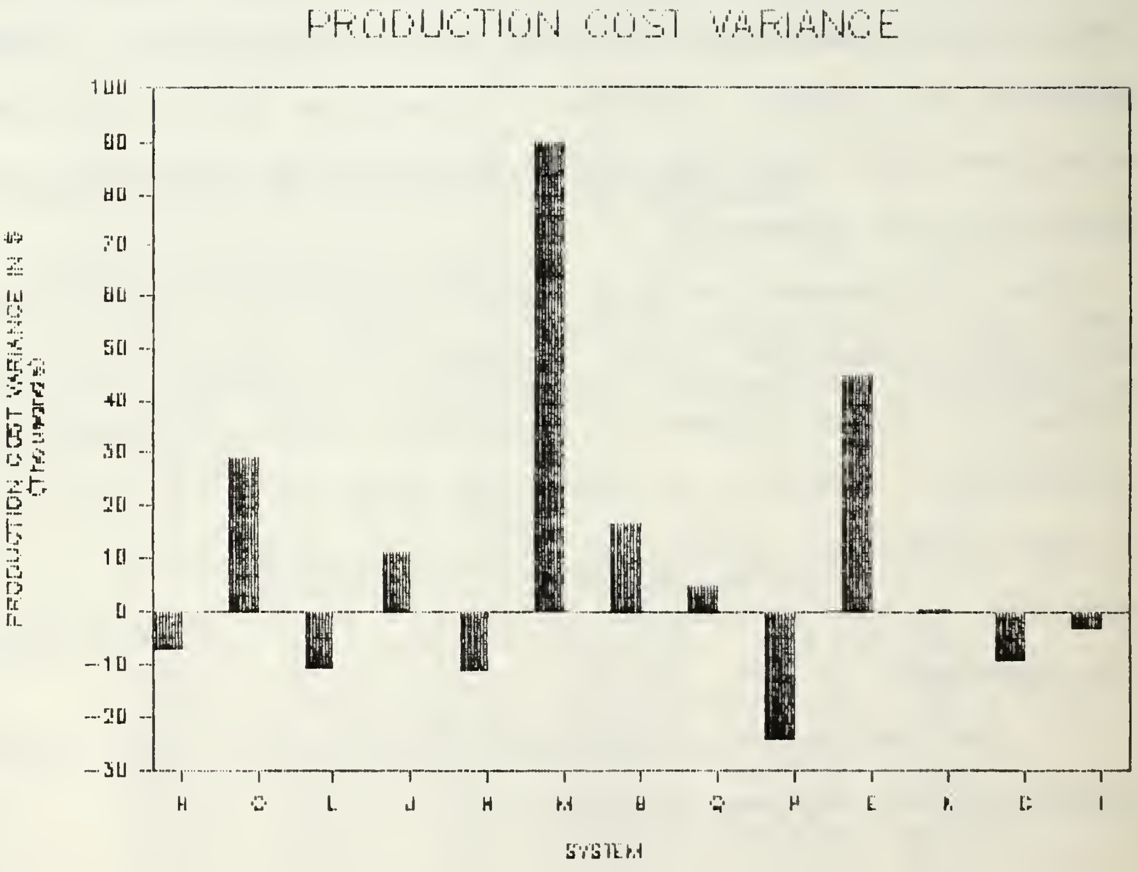


Figure 3.3 Production Costs Variance in Dollars

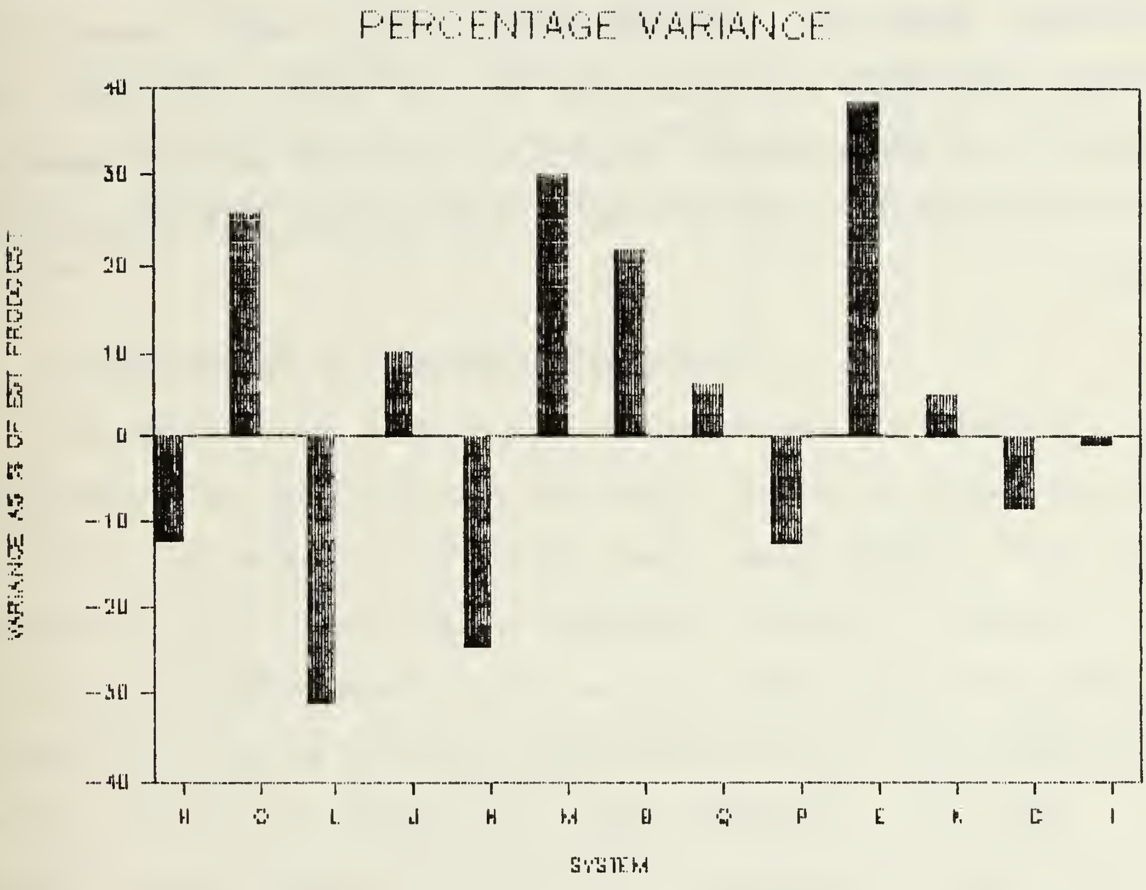


Figure 3.4 Percentage Variance

In order to develop good cost control techniques, it is important that the differences between predicted costs and actual costs be explained. The next two chapters will analyze relationships between cost control (as reflected in the variance measures) and contractor financial condition in order to determine if cost overruns/underruns are associated with financial ratios.

D. SUMMARY

This chapter reported the results of testing hypotheses between measures of production costs and measures of technology, with positive results. The creation of predicted production costs and the resultant variances provide measures of cost control that will be further analyzed in Chapters IV and V.

IV. COST CONTROL AND FINANCIAL CONDITION

A. INTRODUCTION

This chapter contains a discussion of the expected relationships between financial condition of the satellite system manufacturers and cost control, in order to suggest why cost overruns/underruns may be associated with financial ratios. A table of applicable financial ratios to be used for hypotheses testing in Chapter V is also presented, along with a discussion of the data collection process used to obtain necessary information for the analyses presented in Chapter V.

B. THE RELEVANCE OF FINANCIAL CONDITION

The production cost variances developed in Chapter III represent cost overruns and underruns of the various systems studied. If actual production costs were greater then the predicted cost then the resultant variance indicates a production cost overrun. If on the other hand the actual production cost is less then the predicted cost, the variance would indicate a production cost underrun. In order to predict what financial factors of a prospective government contractor may indicate the likelihood of either exceeding or falling below the "norm" for production cost, it is important to look at the financial factors that would tend to

indicate a contractor's propensity to experience production cost overruns or underruns.

The concept of examining financial status by examining the various financial ratios that can be computed using data obtained from published annual financial reports is not new. By looking at relationships between traditional balance sheet and income statement financial data and their possible influence on production, various hypotheses to explain overruns/underruns will be developed. Financial ratios calculated from accounting data contained in financial reports for contractors will be used to represent financial factors or aspects of financial condition. These ratios will be calculated using data from the contract year of each system under study. Hence the data are available prior to actual production.

Financial ratio analysis is a common analytical tool for observing and evaluating the financial condition of the firm. While financial ratio analysis is common, the objective in looking at financial ratios here is non-traditional. Most treatments of ratio analysis presume that the objective of the ratio analysis is to assess the future profitability or risk of a firm. The current objective is more narrowly focused. Ratios will be used as indicators of conditions that may influence production effectiveness or efficiency and consequently have some association with cost overruns and cost underruns.

C. ASPECTS OF FINANCIAL CONDITION

It is possible to categorize financial ratios in many ways. However, several finance and accounting references categorize financial ratios into broad categories representing separate aspects of financial condition as follows: [Ref. 3]

1. **Profitability** (return on investment)
2. **Short-term liquidity**
3. **Solvency** (capital structure)
4. **Activity** (efficiency or turnover)
5. **Capital goods investment**

To simplify the process of analyzing a firm's financial condition, with the goal of predicting the tendency towards production cost overruns/underruns, it is suggested that production costs may depend on these five aspects of financial condition and the specific ratios associated with them. By examining these five aspects of a firm it may be possible to predict a particular firm's propensity towards production cost overruns or underruns prior to a contract being awarded to that firm.

What follows are arguments for links between the five aspects of financial condition and production capability or efficiency. In each case reasons why financial condition may be associated with cost overruns or underruns are discussed. In some cases alternative, even contradictory arguments are offered. The objective here is to explain the possible ways

that financial condition may influence production. Actual relationships between financial condition and production cost control for the sample will be addressed in the report of analysis presented in Chapter V.

Profitability. Because the government often includes penalties for failure to meet specified delivery dates or cost targets, a firm that has shown low profits in the government contractor arena may have experienced past cost overruns or production delays with penalties that reduced profits. This may be an indication of either poor, or unrealistic, production projections or possibly inadequate research and development efforts prior to production. This leads to the hypothesis that low profitability may indicate conditions in which cost incurrence has been poorly managed in the past and, consequently, may reflect a higher propensity for cost overruns on future jobs. For similar reasons, relatively high profitability may signal future cost underruns because of the possibility that higher profitability indicates good past delivery performance, with more dollars available for investment and expansion in production facilities, leading to more efficient production.

On the other hand, excessive profits or consistently high profits may indicate that contractor operations have been successful in the recent past, indicating less need for new business. The contractor is therefore in a stronger negotiating position (assuming non-competitive negotiation)

and can demand a higher price. These "excess" profits (costs to the government) lead to an alternative hypothesis concerning profitability in that high profits may indicate a tendency towards cost overruns.

Short Term Liquidity. Short term liquidity ratios reflect a firm's ability to meet short term financial obligations. These ratios are of major concern to the satellite contractor's suppliers and creditors.

New and updated products may require substantial outlays to finance inventories and production start-up costs. A critical concern in meeting any production schedule is the availability of raw materials and inventory. Because of the perception by the firm's suppliers of greater risk of default, contractors with poor short term liquidity may be more likely to suffer inventory delays and the associated higher costs (less attractive payment/credit terms). This leads to a hypothesis that a firm with poor liquidity is more likely to have production cost overruns.

An alternative hypothesis is also possible. "Excessive" liquidity may be due to high investment in current assets. Current assets are non-productive assets, such as receivables and inventory, and may lead to excessive carrying costs of inventory or lost opportunity cost of funds tied up in receivables. This argument then suggests the hypothesis that high liquidity may be associated with cost overruns. Furthermore, high liquidity is also consistent with high

working capital. Under typical negotiated contracts, the contractor is compensated for carrying working capital. High working capital, therefore, may lead to a higher price and cost overruns.

Solvency. Solvency ratios indicate a firm's ability to meet long-term obligations, both financial and operational. This is the "risk" of a contractor's capital structure and debt repayment ability. Solvency ratios relate long-term debt to various assets or debt expense (interest) to the resources available to pay it. If a firm is experiencing high risk it may be more constrained in production capacity due to the high cost of capital goods financing. This limiting effect reduces the firm's flexibility in production and may even require higher product prices to cover higher debt costs. It is therefore hypothesized that poorer solvency may indicate production cost overruns.

An alternative hypothesis is also possible here. "Good" solvency implies low debt financing, but low debt could indicate insufficient purchases of capital goods to stay competitive with the rest of the industry. If low debt is an indirect indicator of insufficient investment in capital goods, then "good" solvency could be consistent with "poor" production capability and consequently be suggestive of future production inefficiencies. This would lead to the hypothesis that a firm with too little debt would experience production cost overruns.

Activity (Efficiency or Turnover). The "activity" ratios are measured using a sales figure in the numerator and a selected asset figure in the denominator. Thus they relate the amount of resources generated during a period (sales) with assets available to generate the sales. By the very nature of these ratios, measures of specific asset operational or turnover efficiencies are obtained, showing the degree to which resources or capacity are being utilized.

Firms that are fully utilizing existing capacity may be constrained and therefore may be riskier in terms of the flexibility required to meet technologically challenging production. If this is the case, it is hypothesized that firms with high turnover rates may be more likely to experience production cost overruns because of the constraints associated with operating at full capacity.

Alternatively, firms that know how to consistently utilize their resources to maximum potential may be more likely to be able to accurately predict and deliver on a challenging production schedule. If this is the case, it is hypothesized that the more efficient a firm, the more likely the firm is to meet production cost projections. High activity/efficiency ratios would therefore be expected to be associated with production cost underruns.

Capital Goods Investment. Capital goods investment is the largest single asset on the books for most large manufacturing corporations. It is expected that efficient

and competitive firms would be required to invest in capital goods on a continuing basis to both offset depreciation and to keep up with modern manufacturing techniques. This implies major investment in capital goods to be a constant requirement. Outdated or inefficient production facilities could increase costs and result in cost overruns. This would lead to the hypothesis that cost overruns would be more likely if investment ratios are low.

Alternatively, a high level of investment may indicate that a substantial upgrade of production cost facilities has occurred, perhaps due to under investment in the past. Newer assets typically have a higher cost than the ones they replace. This higher cost must be assigned to products produced and thus may lead to increases in the cost of those products. Consequently a high level of investment may be indicative of future cost overruns.

D. SELECTION OF RATIOS

Although many more ratios can be calculated from data available through income statements and balance sheets, the following 23 ratios were considered to be sufficiently comprehensive to represent the five aspects of financial condition for the satellite manufacturing firms.

The ratios and abbreviations that will be used for hypotheses testing in Chapter V are presented in Table 4-1

and are divided into the five financial aspects as discussed previously.

TABLE 4.1

LIST OF RATIOS

CATEGORY Ratio Name	Calculation
PROFITABILITY	
1.Return on Assets (ROA)	Net Income/Total Assets
2.Return on Equity (ROE)	Net Income/S.H. Equity
3.Return on Capital (ROC)	Net Income / Non-Curr. Liab + S.H. Equity
4.Profit Margin (PM)	Net Income/Sales
LIQUIDITY	
5.Current Ratio (CR)	Curr. Assets/Curr. Liab.
6.Quick Ratio (QR)	(Cash + Mkt Sec. +Acct. Rec.) / Curr. Liab.
7.Current Asset Ratio (CAR)	Curr. Assets/Total Assets
8.Working Cap. Ratio (WCR)	(Curr. Assets - Curr. Liab.) / Total Assets
SOLVENCY	
9. Debt Ratio (DR)	Total Liab./Total Assets
10.Equity to Debt (ETD)	S.H. Equity/Total Liab.
11.Curr. Debt Ratio (CDR)	Curr. Liab./Total Assets
12.Non-Curr. Debt Ratio (NCDR)	Non-Curr. Liab./Total Assets
13.Debt to Plant Equip. (DP&E)	Total Liab./Plant & Equip
ACTIVITY/EFFICIENCY	
14.Receivables Turnover (RT)	Sales/Accounts Receivable
15.Asset Turnover (AT)	Sales/Total Assets
16.Plant Asset Turnover (PAT)	Sales/Plant & Equip.
17.Inventory Turnover (IT)	Cost of Goods Sold/Inventory
18.Working Cap. Turnover (WCT)	Sales/(Curr. Assets-Curr. Liab)
INVESTMENT	
19.Investment to Sales (IS)	Investment/Sales
20.Investment to Funds (IF)	Investment/(Net Income + Dep.)
21.Investment to Assets (IA)	Investment/Total Assets

22.Investment to Plant (IP) Investment/Plant & Equipment
23.Investment to Deprec. (ID) Investment/Depreciation Exp.

E. DATA COLLECTION

To obtain needed financial data for hypotheses testing to be reported in Chapter V, a library search was conducted to locate contract year 10-K financial reports of the publicly traded firms involved in the manufacturing of the satellite system. 10-K reports for the contract year were available for companies which manufactured eight different systems (B,C,E,I,L,M,N and Q). Data for system R were not collected because it was deleted as an outlier in the analysis reported in Chapter III. Data for the remaining five systems (H,J,K,O,P) were unavailable from public sources because the contractors were privately held firms at the time of the contract. After contacting each firm's customer relations department, only financial data for system K could be obtained. Unfortunately, the loss of four systems reduced the sample size considerably and may have had an adverse affect on subsequent hypotheses testing.

In general, the objective is to determine if financial aspects can explain variations in production costs/efficiencies in a manner consistent with previously stated relationships. By using ratios closely related to those commonly found in accounting and financial statement analysis text books, assessment of various aspects influencing cost and efficiencies can be pursued. Therefore, the principal objective is to

establish financial ratios that will serve as measures of the previously discussed aspects of financial condition.

V. HYPOTHESES TESTING: COST CONTROL AND FINANCIAL CONDITION

A. INTRODUCTION

This chapter will report the results of tests of hypotheses developed in Chapter IV, to determine if cost overruns/underruns are associated with financial ratios. Because of the resultant small sample size from which the hypotheses testing must be conducted, only correlation and plots were used to test the data. Multivariate regression analysis was to be the test of choice, but the small sample size could lead to erroneous conclusions.

B. SUMMARY OF DATA

The following table is a compilation of all the ratios extrapolated from the 10-K financial reports of the satellite manufacturers, measured at the contract year. It should be noted that all percentage ratios are expressed as a percentage of 100, (i.e. .059 = 5.9 percent).

TABLE 5.1

FINANCIAL RATIOS

RATIO/SYSTEM	Q	E	I	B	L	N	M	C	K
ROA	.070	.059	.071	.056	.043	.014	-.016	.077	.053
ROE	.142	.142	.159	.164	.145	.035	-.041	.177	.118
ROC	.108	.084	.104	.074	.056	.022	-.025	.127	.072
PM	.039	.041	.045	.078	.067	.013	-.010	.059	.033
CR	1.37	1.94	1.80	1.76	1.82	2.02	2.06	1.45	2.00
QR	.303	.824	.942	.989	.894	.446	.923	.940	.833
CAR	.478	.565	.569	.556	.555	.688	.752	.555	.547
WCR	.128	.274	.254	.240	.250	.347	.499	.173	.272
DR	.506	.580	.551	.734	.777	.593	.617	.554	.555

TABLE 5.1 (cont'd)

ETD	.978	.724	.815	.461	.379	.685	.621	.787	.803
CDR	.350	.291	.316	.316	.306	.341	.366	.382	.275
NCDR	.156	.289	.235	.419	.471	.253	.251	.172	.279
DP&E	1.26	2.00	1.89	2.79	3.07	3.30	4.19	1.99	1.31
RT	24.1	6.93	7.75	3.17	3.24	8.70	5.65	5.78	8.03
AT	1.78	1.46	1.57	.715	.630	1.11	1.65	1.30	1.60
PAT	4.43	5.06	5.37	2.72	2.49	6.20	11.20	4.68	3.78
IT	5.31	3.63	4.62	6.39	7.93	2.05	3.69	6.02	4.18
WCT	4.43	5.34	6.18	2.98	2.53	3.21	3.30	7.55	5.87
IS	.009	.011	.015	.028	.038	.024	.024	.008	.011
IF	.161	.171	.205	.159	.219	.539	3.16	.092	.193
IA	.017	.017	.023	.020	.024	.027	.040	.011	.018
IP	.043	.058	.080	.076	.095	.150	.269	.039	.042
ID	.461	.431	.551	.285	.359	.756	1.40	.267	.446

C. HYPOTHESES TESTING

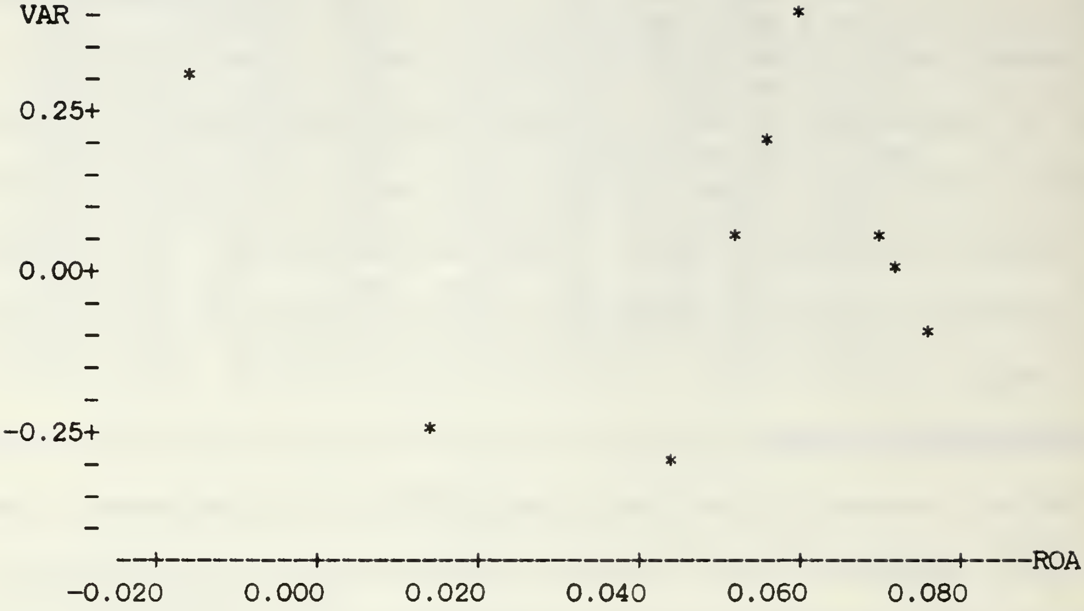
Before reviewing the test results, it is important to note that because of the limited sample size, any conclusion drawn by the results are not conclusive but rather are at best, indications of tendencies represented by the data.

Analysis of Profitability

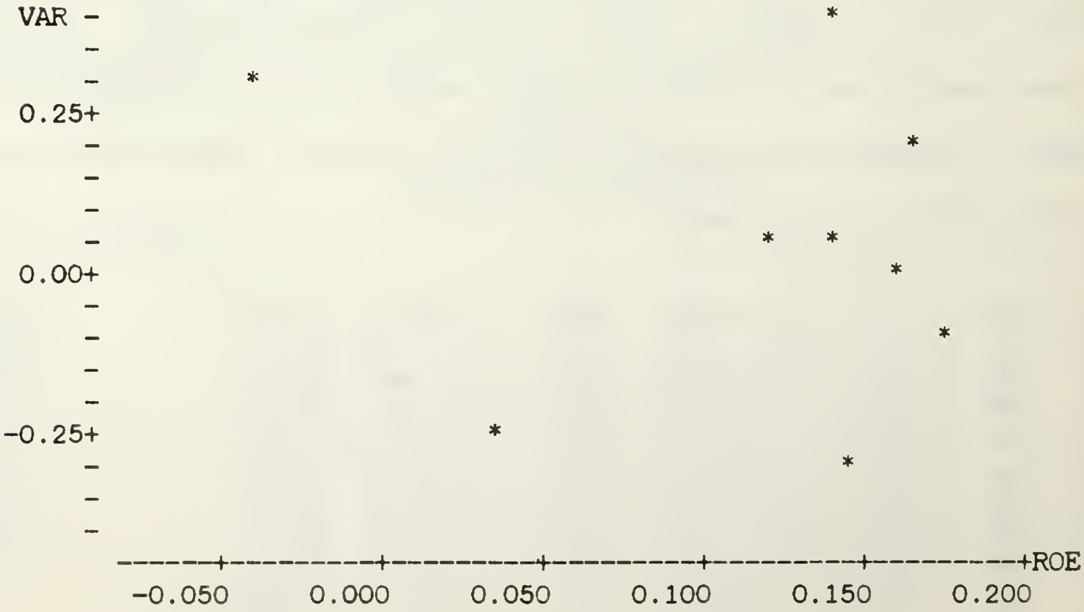
To test the first hypothesis concerning profitability ratios and their effect on production cost overruns/underruns, a correlation and plot of production variance versus the individual profit ratios were conducted with the following results:

SYS	VAR	ROA	ROE	ROC	PM
Q	0.064	0.070	0.142	0.108	0.039
E	0.387	0.059	0.142	0.084	0.041
I	-0.009	0.071	0.159	0.104	0.045
B	0.217	0.056	0.164	0.074	0.078
L	-0.310	0.043	0.145	0.056	0.067
N	-0.246	0.014	0.035	0.022	0.013
M	0.303	-0.016	-0.041	-0.025	-0.010
C	-0.085	0.077	0.177	0.127	0.059
K	0.054	0.053	0.118	0.072	0.033

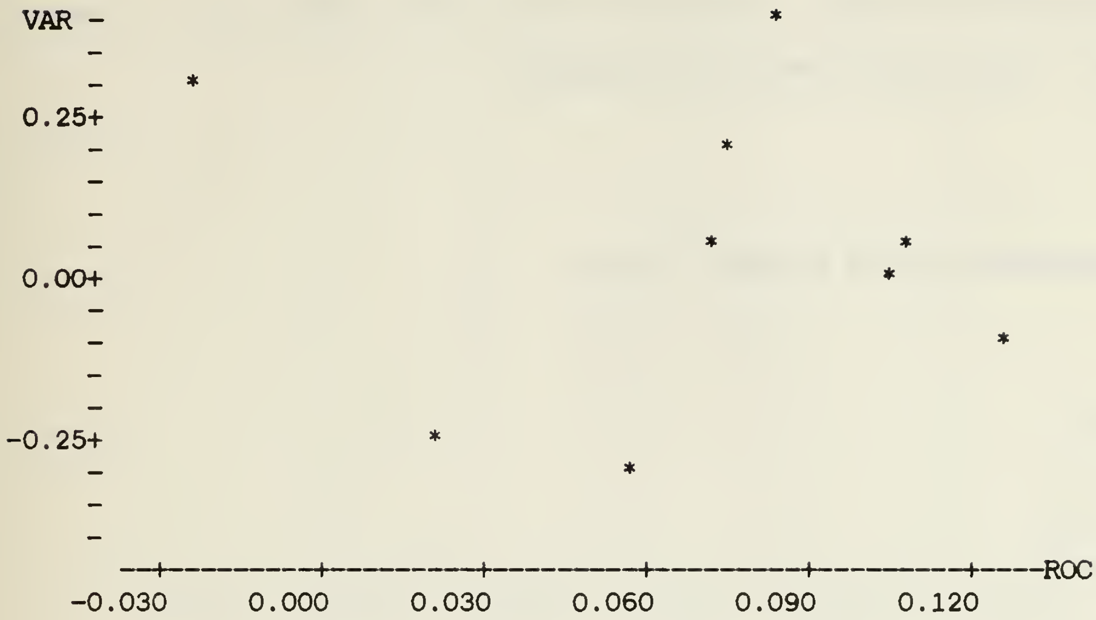
Correlation of VAR and ROA = -0.075



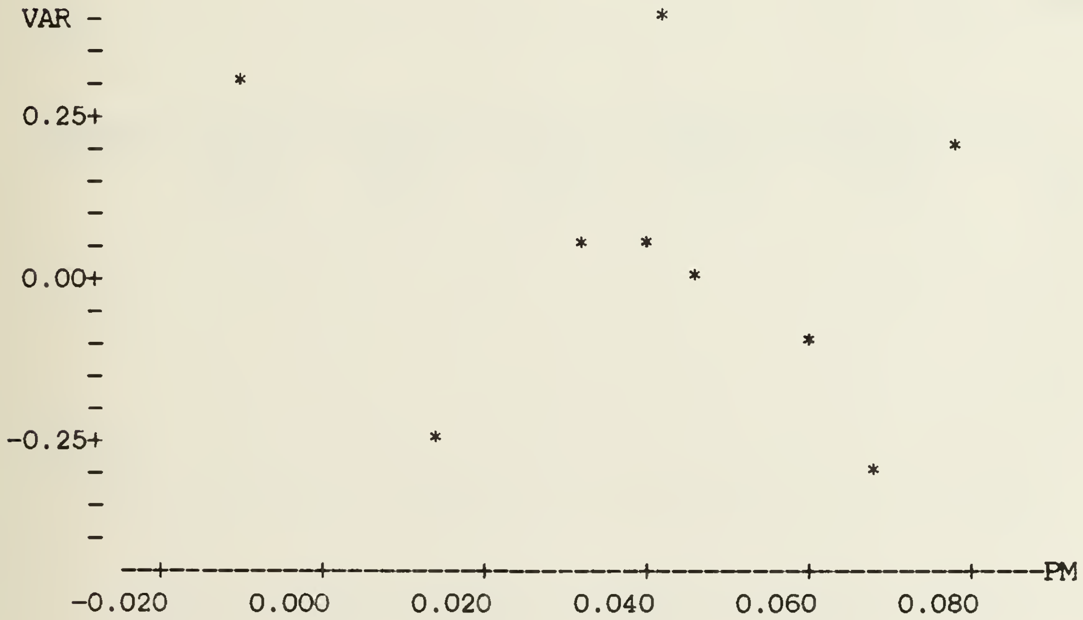
Correlation of VAR and ROE = -0.146



Correlation of VAR and ROC = -0.098



Correlation of VAR and PM = -0.207



The results are rather inconclusive but the plots indicate that system M is an outlier. System M was therefore eliminated and the regression and plots were run a second time. The results were as follows:

Correlation of VAR and ROA = 0.448

```
     VAR -                                        *
         -
         -
     0.25+
         -                                      *
         -
         -
         -                                   *             *
     0.00+                                                  *
         -
         -                                                       *
         -
         -
    -0.25+   *
         -                           *
         -
         -
           +---------+---------+---------+---------+---------+------ROA
       0.012     0.024     0.036     0.048     0.060     0.072
```

Correlation of VAR and ROE = 0.370

```
 VAR -                                          *
     -
     -
 0.25+
     -                                                  *
     -
     -
     -                                  *       *
 0.00+                                                *
     -
     -                                                      *
     -
     -
-0.25+       *
     -                                           *
     -
     -
       ----+---------+---------+---------+---------+---------+--ROE
       0.030     0.060     0.090     0.120     0.150     0.180
```

Correlation of VAR and ROC = 0.360

```
 VAR -                                   *
     -
     -
 0.25+
     -                              *
     -
     -
     -                             *                 *
 0.00+                                             *
     -
     -                                                         *
     -
     -
-0.25+    *
     -                     *
     -
     -
       --+---------+---------+---------+---------+---------+----ROC
     0.020     0.040     0.060     0.080     0.100     0.120
```

Correlation of VAR and PM = 0.131

```
 VAR -                         *
     -
     -
 0.25+
     -                                                        *
     -
     -
     -                   *    *
 0.00+                             *
     -
     -                                        *
     -
     -
-0.25+  *
     -                                               *
     -
     -
       +---------+---------+---------+---------+---------+---------+------PM
   0.012     0.024     0.036     0.048     0.060     0.072
```

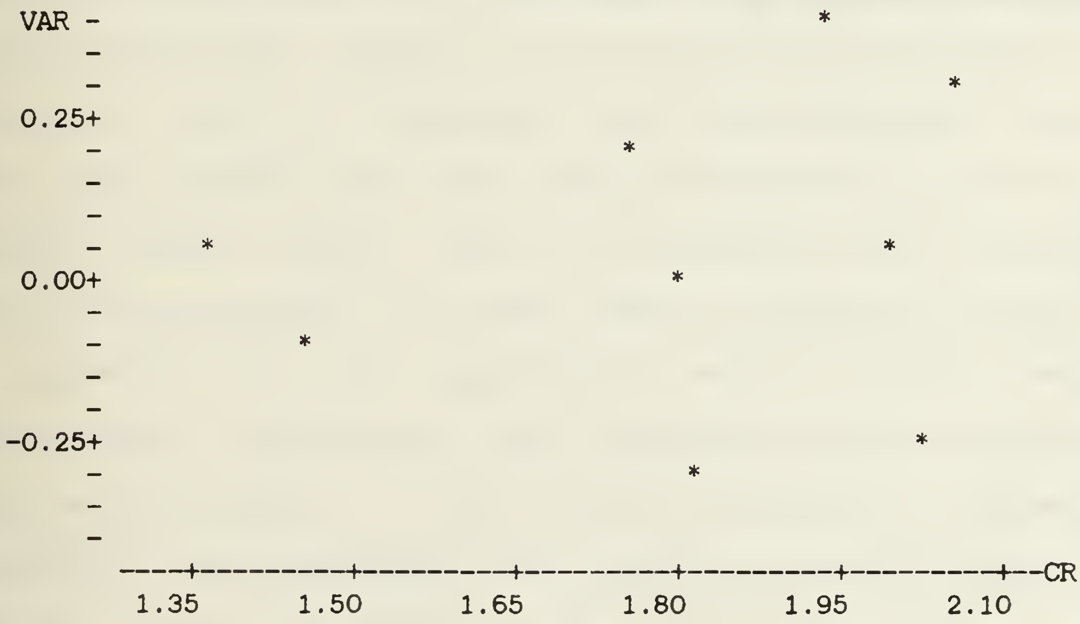
With the outlier removed the profitability ratios appear to be more strongly related to production variances. The positive correlation indicates that firms with high profits tend to have production cost overruns. This is consistent with one of the hypotheses developed in Chapter IV: high profitability implies that a contractor is financially sound and can afford to negotiate from a strong position. The strong negotiation position may permit the contractor to negotiate a higher price than if it were in a weaker position. Thus the higher price is reflected in a higher cost (above that expected given the technology in the system).

Liquidity Analysis

The short term liquidity ratios were the next set of data to be run against the production cost variances to determine their effect on production cost overruns/underruns. The results were as follows:

SYS	VAR	CR	QR	CAR	WCR
Q	0.064	1.37	0.303	0.478	0.128
E	0.387	1.94	0.824	0.565	0.274
I	-0.009	1.80	0.942	0.569	0.254
B	0.217	1.76	0.989	0.556	0.240
L	-0.310	1.82	0.894	0.555	0.250
N	-0.246	2.02	0.446	0.688	0.347
M	0.303	2.06	0.923	0.752	0.499
C	-0.085	1.45	0.940	0.555	0.173
K	0.054	2.00	0.833	0.547	0.272

Correlation of VAR and CR = 0.164



Correlation of VAR and QR = 0.233

```
 VAR -                                          *
     -
     -                                                 *
 0.25+
     -                                                     *
     -
     -
     -       *                                   *
 0.00+                                                  *
     -
     -                                                  *
     -
     -
-0.25+                 *
     -                                               *
     -
     -
       ------+---------+---------+---------+---------+---------+QR
          0.30      0.45      0.60      0.75      0.90      1.05
```

Correlation of VAR and CAR = 0.092

```
 VAR -                     *
     -
     -                                                    *
 0.25+
     -                    *
     -
     -
     -       *          *
 0.00+                      *
     -
     -                   *
     -
     -
-0.25+                                          *
     -                   *
     -
     -
       ------+---------+---------+---------+---------+---------+CAR
         0.480     0.540     0.600     0.660     0.720     0.780
```

Correlation of VAR and WCR = 0.255

```
 VAR -                        *
     -
     -                                                        *
0.25+
     -                   *
     -
     -
     -   *                    *
0.00+                      *
     -
     -          *
     -
     -
-0.25+                                   *
     -                     *
     -
     -
       ----+---------+---------+---------+---------+---------+--WCR
       0.140     0.210     0.280     0.350     0.420     0.490
```

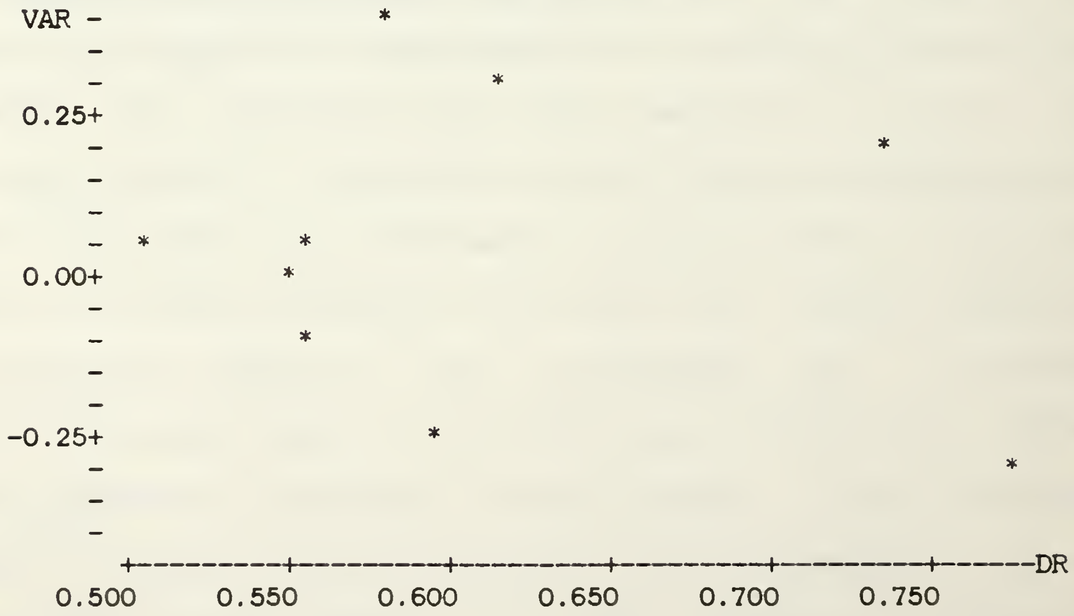
The resulting positive correlation between the short term liquidity ratios and the production cost variances indicate a tendency for high liquidity to be associated with production cost overruns. This is consistent with the hypothesis that a firm with high liquidity may have a high investment in current assets. Because current assets, such as receivables and inventory, are non-productive assets, this may lead to excessive carrying costs of inventory or lost opportunity cost of funds tied up in receivables. Furthermore, high liquidity is also consistent with high working capital. Under typical negotiated contracts, the contractor is compensated for carrying working capital. High working capital therefore, leads to a higher price and cost overruns.

Solvency Analysis

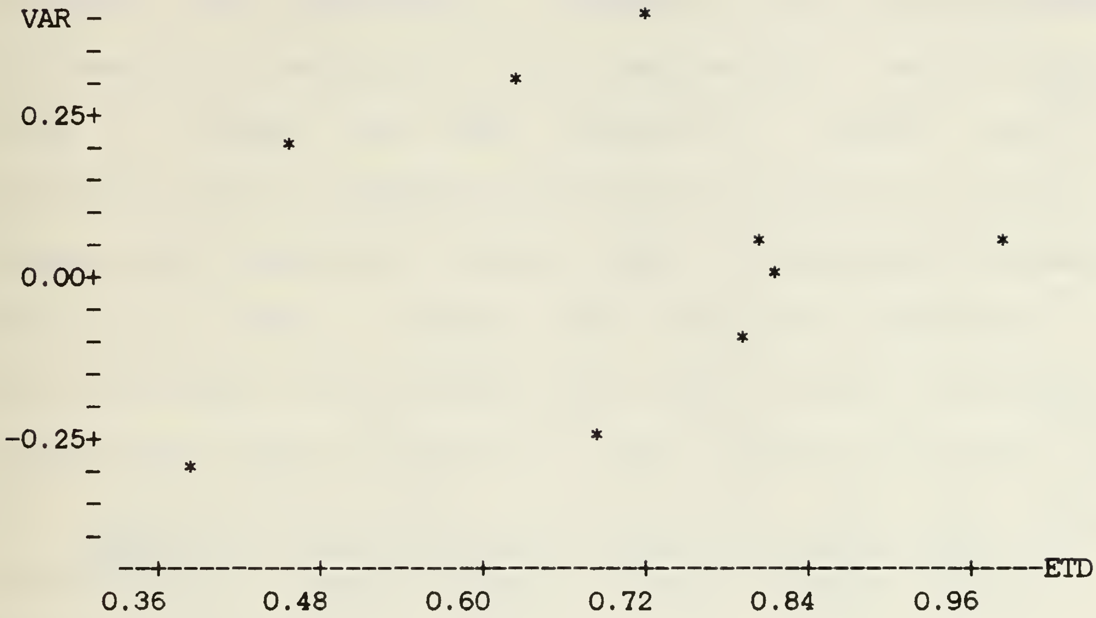
The next set of ratios to be analyzed were the solvency ratios. Correlation and plot results follow:

SYS	VAR	DR	ETD	CDR	NCDR	DPE
Q	0.064	0.506	0.978	0.350	0.156	1.26
E	0.387	0.580	0.724	0.291	0.289	2.00
I	-0.009	0.551	0.815	0.316	0.235	1.89
B	0.217	0.734	0.461	0.316	0.419	2.79
L	-0.310	0.777	0.379	0.306	0.471	3.07
N	-0.246	0.593	0.685	0.341	0.253	3.30
M	0.303	0.617	0.621	0.366	0.251	4.19
C	-0.085	0.554	0.787	0.382	0.172	1.99
K	0.054	0.555	0.803	0.275	0.279	1.31

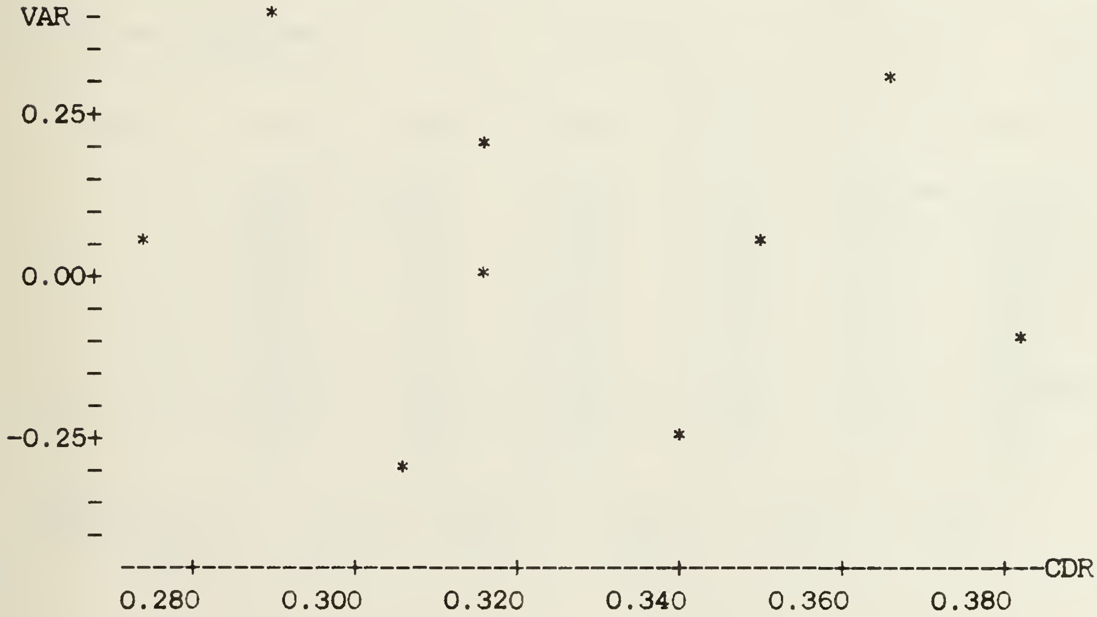
Correlation of VAR and DR = -0.198



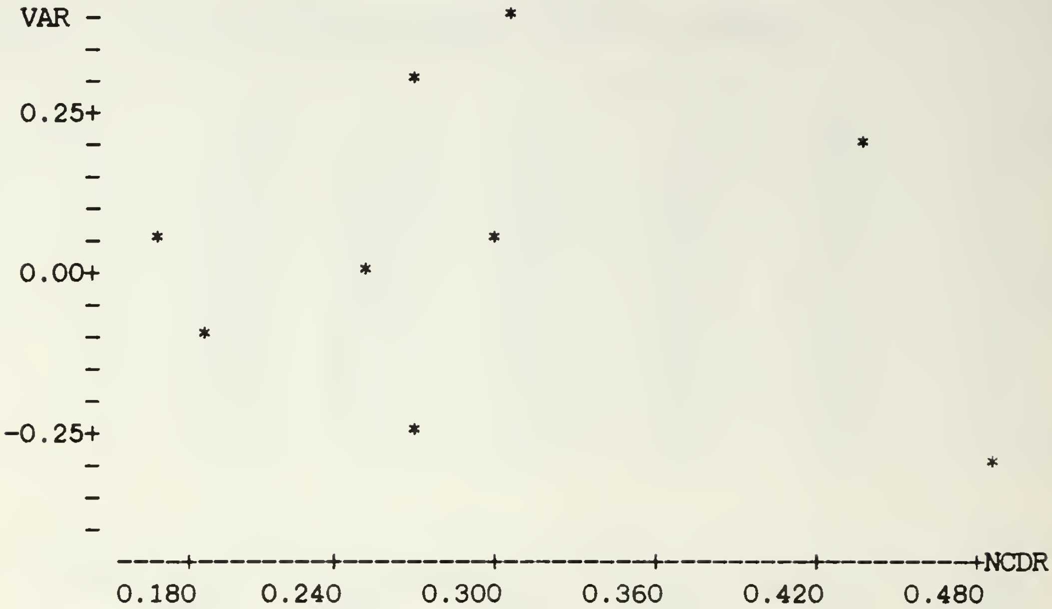
Correlation of VAR and ETD = 0.153



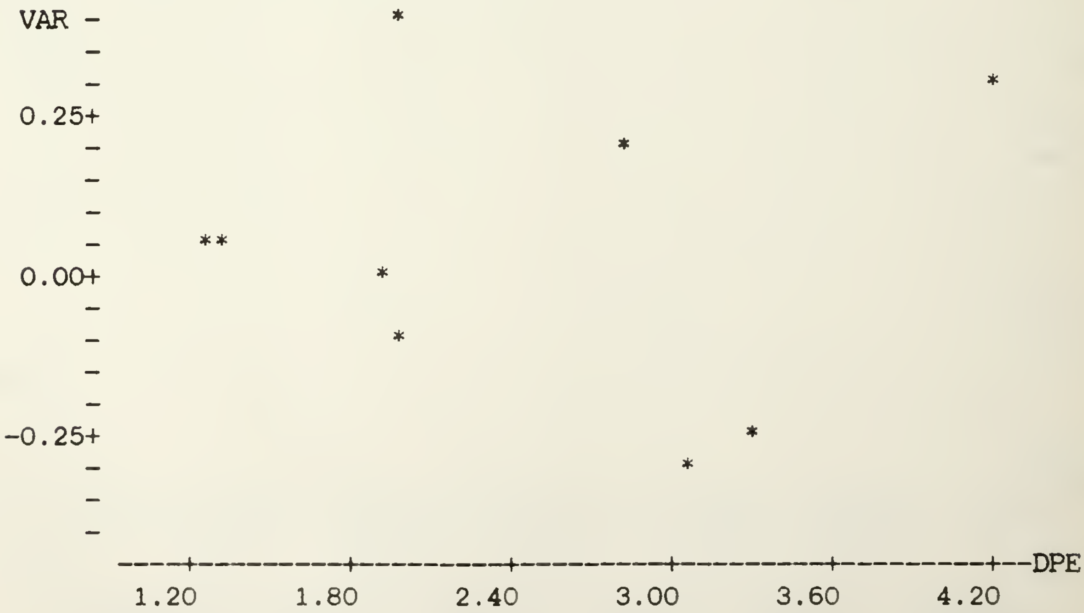
Correlation of VAR and CDR = -0.111



Correlation of VAR and NCDR = -0.134



Correlation of VAR and DPE = -0.031



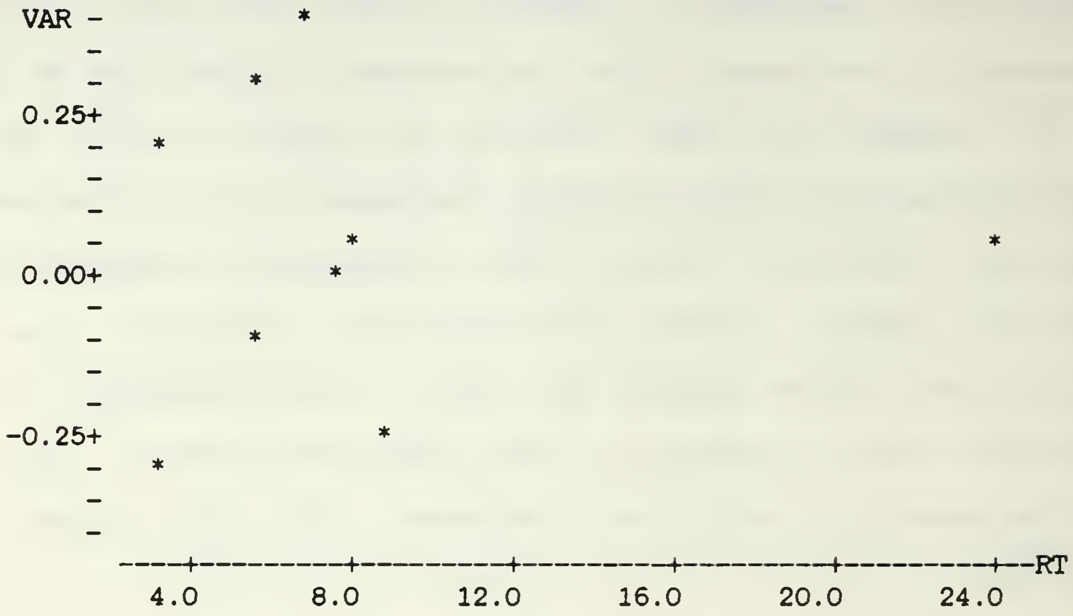
Again the correlations were not very high, but the signs are consistent. As debt increases there is a tendency toward incurring cost underruns. Although firms with higher debt are generally considered to be less solvent, the ability of a firm to finance via debt instead of equity may be an indication that creditors consider the assets of the firm as being more productive (better able to generate revenues to service the debt). Assets that are more productive (i.e. more efficient, more modern) may then be more effective in controlling costs, leading to lower production costs. Such an interpretation would be consistent with the tendency observed.

Activity Analysis

The activity ratios (turnover efficiency with which resources or capacity are being utilized) were the next set of measures to be tested. The following results yielded mixed conclusions:

SYS	VAR	RT	AT	PAT	IT	WCT
Q	0.064	24.1	1.780	4.43	5.31	4.43
E	0.387	6.93	1.460	5.06	3.63	5.34
I	-0.009	7.75	1.570	5.37	4.62	6.18
B	0.217	3.17	0.715	2.72	6.39	2.98
L	-0.310	3.24	0.630	2.49	7.93	2.53
N	-0.246	8.70	1.110	6.20	2.05	3.21
M	0.303	5.65	1.650	11.20	3.69	3.30
C	-0.085	5.78	1.300	4.68	6.02	7.55
K	0.054	8.03	1.600	3.78	4.18	5.87

Correlation of VAR and RT = 0.025



Correlation of VAR and AT = 0.430

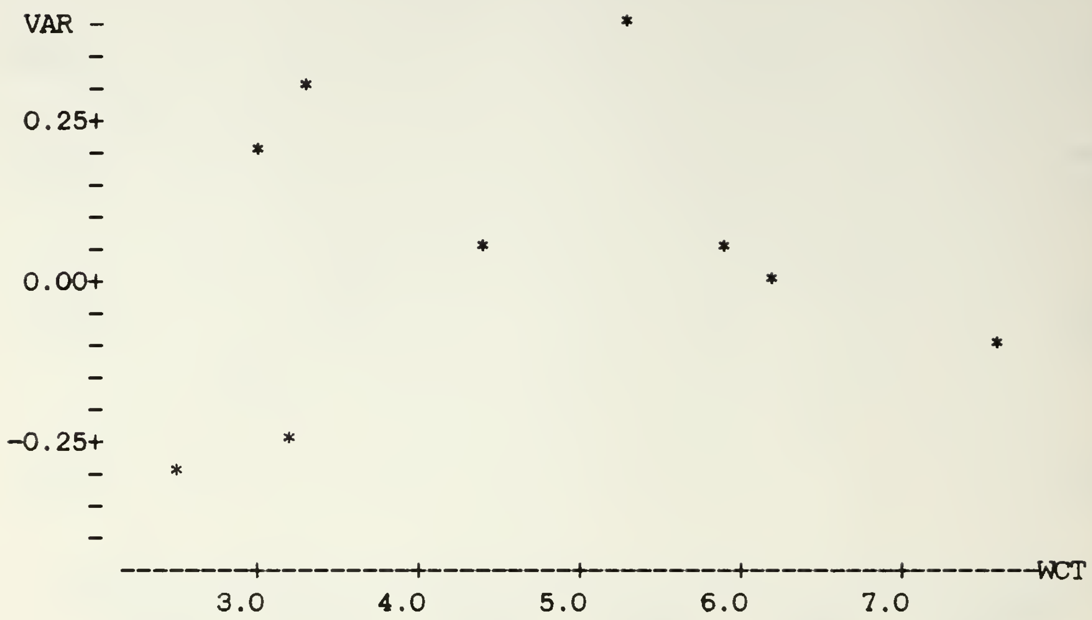
Correlation of VAR and PAT = 0.364

```
 VAR -                   *
     -
     -                                                         *
 0.25+
     -    *
     -
     -
     -           *   *
 0.00+                     *
     -
     -                *
     -
     -
-0.25+                          *
     -   *
     -
     -
       ------+---------+---------+---------+---------+---------+PAT
           3.2       4.8       6.4       8.0       9.6      11.2
```

Correlation of VAR and IT = -0.262

```
 VAR -                   *
     -
     -                    *
 0.25+
     -                                          *
     -
     -
     -                        *        *
 0.00+                           *
     -
     -                                       *
     -
     -
-0.25+      *
     -                                                       *
     -
     -
       --------+---------+---------+---------+---------+--------IT
             2.4       3.6       4.8       6.0       7.2
```

Correlation of VAR and WCT = 0.097



With the exception of the inventory turnover ratio, the remaining activity ratios indicate a tendency for firms with high activity ratios to have cost overruns. This could be an indication that, although contractors are using their existing assets efficiently, they are operating at full capacity. The contractors may be constrained and are thus not as flexible as they might otherwise be. Constraints on operations could lead to the observed cost overruns.

On the other hand, the inventory turnover ratio indicates that a firm that efficiently turns over its inventory is efficiently managing its inventory, reducing carrying costs, leading to cost underruns. High inventory turnover also is consistent with a greater ability of firms to deliver on a production schedule, resulting in cost underruns.

Investment Analysis

The final analysis concerns the capital goods investment ratios. Correlation and plots for each ratio follow: (Two plots for ratio IS are shown. The reason for this will be explained following the plots.)

SYS	VAR	IS	IF	IA	IP	ID
Q	0.064	0.009	0.161	0.017	0.043	0.461
E	0.387	0.011	0.171	0.017	0.058	0.431
I	-0.009	0.015	0.205	0.023	0.080	0.551
B	0.217	0.028	0.159	0.020	0.076	0.285
L	-0.310	0.038	0.219	0.024	0.095	0.359
N	-0.246	0.024	0.539	0.027	0.150	0.756
M	0.303	0.024	3.160	0.040	0.269	1.400
C	-0.085	0.008	0.092	0.011	0.039	0.267
K	0.054	0.011	0.193	0.018	0.042	0.446

Correlation of VAR and IS = -0.345

```
     VAR -         *
         -
         -                                *
     0.25+
         -                                       *
         -
         -
         -      *  *
     0.00+                *
         -
         -    *
         -
         -
    -0.25+                                *
         -                                                      *
         -
         -
           +---------+---------+---------+---------+---------+---------+------IS
      0.0060    0.0120    0.0180    0.0240    0.0300    0.0360
```

Correlation of VAR and IS = 0.476

```
VAR -             *
    -
    -
0.30+                                             *
    -
    -
    -                                                       *
    -
0.15+
    -
    -
    -       *     *
    -
0.00+                       *
    -
    -
    -     *
      ----+---------+---------+---------+---------+---------+--IS
     0.0080    0.0120    0.0160    0.0200    0.0240    0.0280
```

Correlation of VAR and IF = 0.357

```
 VAR -    *
     -
     -                                                      *
 0.25+
     -    *
     -
     -
     -    2
 0.00+    *
     -
     -   *
     -
     -
-0.25+          *
     -     *
     -
     -
       +---------+---------+---------+---------+---------+------IF
    0.00      0.60      1.20      1.80      2.40      3.00
```

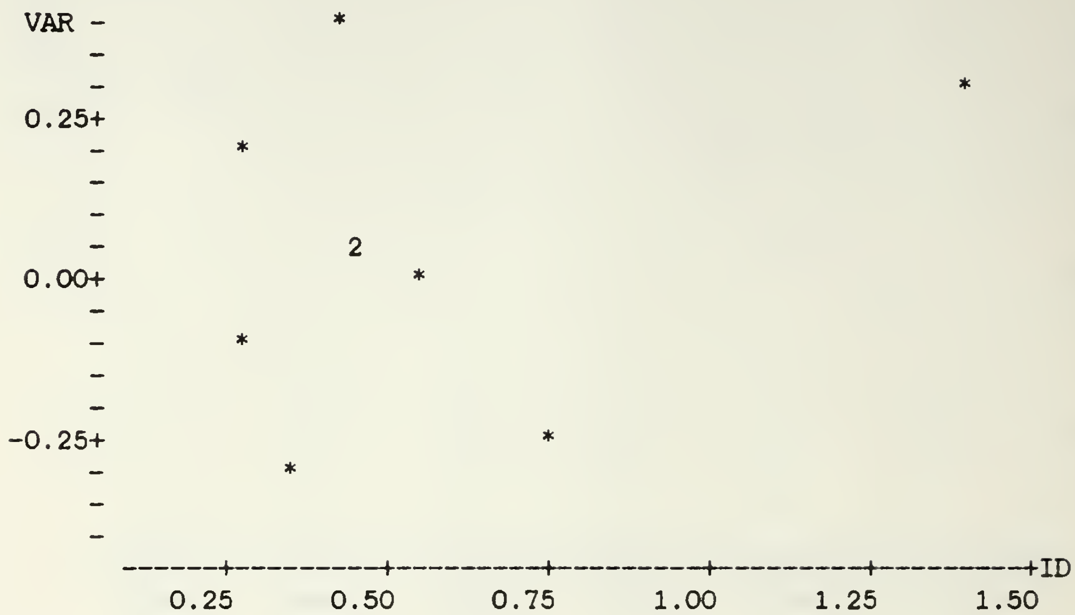
Correlation of VAR and IA = 0.107

```
 VAR -               *
     -
     -                                                      *
 0.25+
     -                    *
     -
     -
     -               * *
 0.00+                         *
     -
     -     *
     -
     -
-0.25+                                *
     -                           *
     -
     -
     -
       ------+---------+---------+---------+---------+---------+IA
        0.0120    0.0180    0.0240    0.0300    0.0360    0.0420
```

Correlation of VAR and IP = 0.140

```
 VAR -           *
     -
     -                                                     *
 0.25+
     -              *
     -
     -
     -       **
 0.00+               *
     -
     -       *
     -
     -
-0.25+                             *
     -                  *
     -
     -
     -
       --------+---------+---------+---------+---------+--------IP
           0.050     0.100     0.150     0.200     0.250
```

Correlation of VAR and ID = 0.265



The results indicated a tendency for firms with more investment in capital goods to produce systems with cost overruns. This finding is consistent with one of the hypotheses. A large investment may indicate the replacing of older assets which, although more modern, are more expensive. When the higher cost of the newer assets is assigned to the product, higher production cost follows and cost overruns result.

The only exception to this was the investment to sales ratio. Further examination of the plot indicated that systems L and N were outliers. System L and N were eliminated and the plot and correlation was run a second

time. The association was then positive, corresponding to the results of the other investment ratios.

D. SUMMARY

This chapter reported the results of testing of hypotheses between cost control (as reflected in the variance measures) and contractor financial condition, with varied results. It is again stressed that the limited sample size allows only the observation of general tendencies and does not permit a multivariate analysis which would have resulted in better control over the analysis of statistical relationships. On the positive side, the findings for the individual ratios within each category were generally consistent and some broad tendencies were observable in the data.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The purpose of this thesis was twofold: (A) to determine relationships between advances in technology and production costs, for a sample of satellite systems, and (B) to determine relationships between contractor financial condition and control of production costs. Accomplishment of these goals involved the following steps:

Chapter I introduced the thesis objective and provided a background and motivation for the study. In addition, the chapter briefly reviewed Dr. Greer's study as well as described the differences between his study and this thesis, with particular emphasis on production costs and cost control versus contractor financial condition. The chapter concluded with a detailed organization of the thesis.

Chapter II involved a detailed review of Dr. Greer's study. The intent of this chapter was to gain an understanding of Dr. Greer's methods of sample and data collection, the procedures he used to arrive at technology measures and the relationships he established between technology and development cost. As a similar analysis was to be conducted using production costs, it was important to understand the relationships between technology extension and development costs. Dr. Greer's analysis provided three

measures of technology or technology extension (advance, redesign and reach), three measures of development cost (actual, ex ante, and estimated based on actual time) and two cost variances (variance due to time and cost control variance). The chapter concluded by providing the new measures of production costs to be used for hypotheses testing in Chapter III.

Chapter III reported the results of testing of hypotheses between measures of production costs and measures of technology, with significant results. No direct relationship between technology measures and production cost was found. However, production cost was found to be strongly related to development cost and the ratio of development cost to production cost was found to be significantly related to measures of technology. Development cost was larger, relative to production cost, when a large technological advance was required in developing a system. Of importance in this chapter was the construction of measures of predicted production costs as a function of measures of technology and development costs. In order to develop good cost control, it is important that the differences between predicted costs and actual costs be explained. The creation of the predicted production costs and the resultant variances provided measures of cost control that were further analyzed in Chapters IV and V.

Chapter IV presented an analysis of the expected relationships between financial condition of the satellite system manufacturer and cost control. The objective was to suggest why cost overruns/underruns may be associated with financial ratios. In this chapter alternative, sometimes contradictory, arguments were offered for why each of the five aspects of financial condition might influence production cost and hence explain production cost variance. The five aspects of financial condition discussed were profitability, leverage, liquidity, activity and capital investment. The discussion suggested why these aspects of financial condition might affect a contractor's production capability or efficiency. The chapter concluded with a discussion of the data collection process used to obtain the necessary information for the analysis conducted in Chapter V.

Chapter V reported the results of testing of hypotheses developed in Chapter IV, in order to determine if cost overruns/underruns are associated with financial ratios.

When testing profitability ratios, there was a tendency for a firm with high profits to incur cost overruns. This is consistent with the hypothesis that a contractor that is financially sound can afford to negotiate from a strong position and seek a higher price, which is reflected in a higher cost.

In analyzing liquidity, there was a tendency for highly liquid firms to overrun production costs. This is consistent with the hypothesis that a firm with high liquidity may have a high investment in current assets. Because current assets, such as receivables and inventory, are non-productive assets, this may lead to excessive carrying costs of inventory or lost opportunity cost of funds tied up in receivables. The high liquidity is also consistent with high working capital. Under typical negotiated contracts, the contractor is compensated for carrying working capital. High working capital therefore, leads to a higher price and cost overruns.

When long term debt was tested the results indicated that as debt increased there was a tendency towards observing cost underruns. This suggests that the ability of a firm to finance via debt instead of equity may be an indication that creditors consider the assets of the firm as being more productive. More productive assets may create efficiencies in controlling costs.

When testing activity ratios, mixed results were obtained. With the exception of the inventory turnover ratio, the remaining activity ratios indicated a tendency for firms with high activity ratios to have cost overruns. Interpreting turnover ratios is uncertain. A high turnover ratio is sometimes viewed as an indicator of efficient operations. However, a high turnover ratio is also consistent with a firm operating near full capacity.

Operating at full capacity may place constraints on further production, resulting in the cost overruns observed. The inventory turnover ratio however, indicated that a firm that efficiently turns over its inventory may be better able to deliver on a production schedule, resulting in cost underruns.

The final analysis concerned the capital goods investment ratios. Results indicated a tendency for firms with more investment in capital goods to produce systems with cost overruns. This was consistent with the hypothesis that a large investment may indicate the replacing of older assets with newer assets which are more expensive. The higher costs of the new assets result in higher production costs and therefore cost overruns.

B. RECOMMENDATIONS

The conclusions reached by this thesis suggest two recommendations.

From a cost estimation point of view, the analysis aides in the determination of future production costs for satellite technology advances. It is important for a cost estimator to understand the relationships between the overall technological complexity of the system and the resulting effects on production costs. If this is understood than a model could be used to develop predicted production costs

which could be used as an aide for enhanced cost control techniques/systems.

From the government's point of view, understanding the effects the contractor's financial condition has on its ability to meet costs is of importance. Based on the tendencies discussed in this thesis, the government should review the financial health of a firm prior to entering into a contract in order to determine its propensity towards cost overruns/underruns. However, it is important to once again note that because of the limited sample size, any conclusion drawn by the results are not conclusive but are, at best, indications of tendencies in the data.

This limitation in data was the major obstacle encountered when conducting this research. It is therefore recommended that any further study involving the analysis of financial ratios be conducted with a sample size large enough to avoid the possibility of developing erroneous conclusions. A further benefit of a larger sample size would be the possibility of additional testing to include multivariate regression. This technique would result in better control over the analysis of statistical relationships.

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